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DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 61 ~67, 69~72

SOME FOREIGN SPECIFICATIONS FOR RAILWAY MATERIALS:

RAILS, WHEELS, AXLES, TIRES

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Bureau of Standards

ISSUED APRIL 20, 1916

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29.11.23

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SOME FOREIGN SPECIFICATIONS FOR RAILWAY MATERIAL: RAILS, WHEELS, AXLES, TIRES

By G. K. Burgess and P. D. Merica

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I. INTRODUCTION

As a part of the Bureau's program relating to the determination of the causes of failure of railway materials, such as wheels, rails, axles, etc., as authorized by Congress, it was considered advisable to find out what is the European practice with respect to specifications for and tests of such types of material, together with any information available concerning the prevalence of accidents abroad caused by failure of railway equipment.

In pursuance of this idea the Department of State was asked to aid in the securing of the desired information, in accordance with the following letter of July 22, 1913:

The Department of Commerce, in view of an investigation by the Bureau of Standards of railway material in the United States, requests that the Governments of Austria-Hungary, Belgium, France, Germany, Great Britain, Holland, Italy, Russia, and Sweden be asked through the Department of State to furnish, if possible, information on the following matters:

The laws, regulations, or specifications now in force and when adopted covering the processes of manufacture and methods of inspecting and testing of wheels and axles for freight and passenger cars and locomotives, and what types and sizes of wheel and axle are used or permitted for the several classes of service; analogous

information concerning rails; statistics as to the number of derailments and their causes as apportioned among defective wheels, axles, rails, and other defective equipment or permanent way.

As a result of this inquiry the consuls general of the United States resident in the several countries mentioned took great pains to secure as complete data as possible; and their requests for information were cordially responded to by the several railway administrations, whether under governmental or private control.

The Bureau of Standards takes this opportunity of expressing its appreciation of the effective cooperation by the Department of State and of the foreign railway administrations; and it is hoped that the information thus obtained may be of some interest and service to the railways and manufacturers of railway material in the United States, in that it gives an opportunity to compare American and European practice for some of those portions of railway equipment which are most subject to the failures causing accidents.

There are also included some accident statistics which, however, are to be considered mainly as indicative of their relative frequency in the several countries, and as caused by failure of railway material. An exact comparison can not be made on account of different classifications and methods used in reporting accidents.

The discussion and comparison of the several types of foreign specifications and tests of rails, wheels, axles, and tires, treated by subjects, forms the main text of the report, while the detailed specifications and descriptions of tests are given by countries in the appendix.

The authors take this opportunity of expressing their appreciation of the aid rendered in the translation of the Italian specification to Mr. A. Fanti and in the translation of the Swedish specification to the Bureau of Foreign and Domestic Commerce.

II. SOME ACCIDENT STATISTICS

The data gathered relative to the number and causes of accidents are shown in Table 1, in which there is also included for comparison similar figures for the United States, culled mainly from the reports of the Interstate Commerce Commission. The foreign figures are evidently, in many cases, very incomplete, and the basis of computation is not a common one for the various countries, so that strictly exact numerical comparisons with the American figures can not be made. Nevertheless, there is sufficient information available in the table to draw some fairly trust-

worthy conclusions concerning the relative prevalence of accidents due to faulty equipment abroad and at home.

The number of failures would be expected to bear some relation to the density of traffic, both passenger and freight, unless there existed a marked difference in quality of material in going from one country to another.

The railroads of Great Britain and Ireland, for example, carried in one year over 3000 million passengers and 520 million tons of freight with only 24 derailments from all causes causing injury to persons. In these accidents 209 persons were injured, of which 13 were killed. For the same period in the United States there were carried a third as many passengers (1004 millions), but somewhat over three times the freight (1844 million tons), over 183 000 miles of track; but there were from 4000 to over 5700 derailments, in which 5000 to 7500 persons were injured.

In Table 1 are also given the number of derailments per million passengers carried and per thousand miles of track for the countries for which these data are available, namely, Austria, Germany, the United Kingdom, and the United States. This shows 26 times as many derailments per mile of track for the United States as for Great Britain and 3 times as many as for Germany, but only one-third the Austrian record. In terms of passengers carried, the Austrian and American derailments are not very different, but the American are nearly 600 times the British and 24 times the German. An inspection of the table shows also low accident or derailment figures for France, Russia, and Sweden, there being, for example, about one passenger injured, due to derailments, per two million carried in France as against 14 for the United States.

There appear to be but few foreign statistics available concerning the removal for defects of such railway materials as rails, wheels, and axles. Such statistics are of interest as giving a measure of quality of each type of material or equipment for the service intended.

Some data of this sort on rails are given in a series of articles by Fremont.[1] He says:

> Rail breakages are very frequent. In France it is calculated that there are from 2500 to 3000 per year. * * * In France the percentage of yearly breakages is about one per 2000 rails in service. * * * In 1898 there were 3223 rail breakages on the 33 674 km of railroads of Austria-Hungary, about one failure per 2000 rails; on the 88 135 km of German railroads there were 13 504 failures; that is, about one per 1350 rails.

[1] Le Genie Civil, vol. 59, 1911, p. 7.

He quotes from a report by M. Callon, 1910 (Minister of Public Works), showing that the number of such failures in proportion either to the total length of track or to the total number of rails in track is growing rapidly in France. Thus there were the following percentages of increase of failures:

Railroad	Per cent increase	Period
Midi	230–260	5 years, 1904–1908.
de l'Est	160–190	
d l'Ouest	40–50	
du Nord	4–20	4 years, 1904–1907.
d'Orleans	60–75	5 years, 1904–1908.
P. L. M.	10–20	4 years, 1904–1907.

Such data for the United States could perhaps be obtained from the records kept by the railroads, and, in fact, are available for rails in the reports of the American Railway Engineering Association, from which it appears that there were removed from the tracks in 1911 for defects 36 641 rails for 12 688 714 tons laid, and in 1912, 61 047 failed rails for 13 736 956 tons, or in 1912 there was a potential accident for 1 in about every 470 rails in the track in the United States, which possible accident was presumably prevented only by the track-inspection service of the railroads. That there were, nevertheless, 363 derailments caused by defective rails in 1912, 1255 caused by wheels, and a total of 5724 derailments in one year caused by defective equipment or track, points to the desirability of examining the question of the improvement of specifications and tests of at least some of the railway material, the failure of which may cause accidents.

It was with the object of putting the European practice in these matters before those in the United States interested in and responsible for railway matters that these foreign specifications have been secured. European practice is believed to be of interest for one reason, among others, that the foreign railway materials, such as rails, wheels, and axles, appear to perform the duty imposed upon them in a more adequate manner, generally speaking, than is the case in America.

TABLE 1

Statistics Concerning Derailments

Country	Year	Derailments on account of—				Total per year	Persons injured per year	Miles of track	Passengers carried per year in millions	Tonnage carried per year in million tons	Derailments	
		Rails	Wheels	Axles	Miscellaneous						Per 1000 miles of track.	Per million passengers
Austria	1912	[a] 56	[b] 86	.....	[c] 1301	1443	(*d*)	20 563	[e] 276	[e] 136	71	5. 2
United Kingdom	1911	257	82	91	[f] 4187	[g] 4617	.....	23 200	3127	523	.....	.....
	1912	265	83	93	[f] 3909	[g] 4350	[h] 209	.....	.....	.....	.....	.....
	1912	[i] 1	[i] 4	.....	[i] 19	[i] 24	[j] 703	.....	.....	.....	[i] 1	[i] 0. 008
France [k]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Russia	1906	.....	.....	.....	.....	223	.....	.....	.....	.....	.....	.....
	1907	.....	.....	.....	.....	241	.....	.....	.....	.....	.....	.....
	1908	.....	.....	.....	.....	227	(*d*)	.....	.....	.....	.....	.....
	1909	.....	.....	.....	.....	197	.....	.....	.....	.....	.....	.....
Sweden	1910	44	.....	.....	.....	[g] 44	.....	.....	.....	.....	.....	.....
	1911	66	34	2	.....	[g] 102	.....	8677	[l] 18	[l] 11	.....	.....
	1911	[i] 0	[i] 2	[i] 0	.....	[i] 2	.....	.....	.....	.....	.....	.....
	(*m*)	[i] 0	[i] 0. 8	[i] 1	.....	[i] 1. 8	.....	.....	.....	.....	.....	.....
Germany	1911	[a] 53	7	13	233	306	(*d*)	38 747	[n] 1541	[n] 531	8	0. 2
United States	1911	249	997	355	2448	[o] 4049	5148					
	1912	363	1255	410	3696	[o] 5724	7541	183 000	1004	1844	[p] 26	[p] 4. 7
	1913	340	1223	474	2329	[o] 4366	6868					
	(*q*)	220	939	343	2350	[o] 3852	.....	.....	.....	.....	.....	.....

[a] Includes permanent way.
[b] Includes other defects of rolling stock.
[c] Includes signals, carelessness, etc.
[d] In 1908 there were 2855 passengers injured in Austria, Germany, and Russia combined.
[e] Figures relate to 1911.
[f] Includes over 2400 broken couplings.
[g] Total accidents whether causing derailment or not.
[h] From derailment (13 killed).
[i] Accidents causing injury to persons.
[j] Total injured on railways due to railway defects.
[k] For the 12-year period from 1895–1906 detailed data were not available in all particulars. However, in 1904 only 0.17 per million were injured by reason of derailments, and in 1906, 0.73 per million. During 4 years of this period there were no deaths due to railway accidents.
[l] Figures relate to 1909.
[m] Average for the 6 years 1906–1911.
[n] Figures relate to 1910.
[o] Accidents causing injury to persons or loss of property.
[p] Average of 1911, 1912, and 1913.
[q] Average for the 11 years 1902–1912.

III. DISCUSSION AND RÉSUMÉ OF SPECIFICATIONS

There are given in the appendix specifications for railway materials, rails, axles, tires, and wheels from the following countries: The United Kingdom, Italy, France, Belgium, Germany, Austria, Holland, and Sweden. It will be noticed that these specifications fall into groups, one group being formed by the United Kingdom; one by France, Italy, and Belgium; and one by Germany, Austria, Holland, and Sweden. The variations in the specifications within each group are less marked than those between groups.

1. AUTHORITY OF SPECIFICATIONS

The railways of the different countries of which specifications are given here are differently organized, and whereas in one case these specifications may be issued by the Government itself through its railway administration, in other cases the specifications are no concern whatever of the Government, but are drawn up and issued solely by the privately owned railroads.

In the United Kingdom the railroads are all privately owned and each railroad naturally issues its own specifications. Nevertheless, "approximately 60 per cent of the construction by railway companies conforms to the specifications published by the Engineering Standards Committee, a semiofficial organization supported by voluntary associations and by the Government; and when these specifications are not followed by the railroads, those issued by the latter conform more or less closely to them.[2]

In 1907 the railway clearing house drew up some specifications for the construction of "private owner's waggons," [3] and while these hold primarily for freight cars owned by private firms or individuals, "it is stated by a general manager of one of the English railways that these are adhered to generally by the railways in the construction of their own cars." [4]

In Italy the railroads are practically all owned and administered by the State and specifications drawn up and issued by the State Railway Administration.

In France the railways are privately owned, with the exception of the Western Railways and a southern line comprising the State Railway System, and specifications are issued by each of these

[2] Quotation from letter from Deputy Consul General Loop at London, 1913.
[3] The English term for freight car.
[4] Quotation from letter (1913) from Deputy Consul General Loop at London.

railways. Since 1901, however, much effort has been made to unify these specifications, such that with few exceptions there exist French standard or unified specifications for such equipment. These are published.[5]

Specifications of the four principal French railroad systems are given in the appendix.

The railroads of Belgium are practically all State railroads, and the specifications of the State Railway Administration are given in the appendix.

The railways of Germany are practically all State owned; that is, they are, for the most part, owned and operated by the various German States. Specifications issued for the Prussian and Prussian-Hessian railways are given in the appendix, together with those of the several associations, official or semiofficial, such as the Association of German Railway Administrations and the German State Railway Car Association.

The railways of Austria are also practically all State owned, and in the appendix are given the Austrian Government specifications for railway material.

In Holland the railways are all privately owned, and specifications as issued by four of the largest railway companies in Holland are given in the appendix.

About one-fourth of the Swedish railways are State owned. The specifications given in the appendix are issued by the Royal Administration of State Railways.

2. TYPES OF RAILS AND ROLLING STOCK

It is generally known that the service conditions to which rails, wheels, and axles are subjected in the United States are in many respects more severe than in the United Kingdom or on the Continent. The rolling stock is generally lighter abroad, although the tendency has been in recent years in the direction of heavier equipment; and the rails are practically as heavy as American rails, or, relative to the service, they are, in general, much heavier.

In Table 2 are given the weights of the types of rails used on the foreign railways at present.

[5] Cahiers des Charges des Compagnies de Chemins de Fer. Quai des Grand Augustins 49, Paris.

TABLE 2
Weights of Various Foreign Rail Types

Country and railway	Date	Weight of rail in pounds per yard	Weight of rail in kilograms per meter
United Kingdom (Engineering Standards Committee):			
Bullhead rails	.....	50–100	.....
Flat bottom rails	.....	50–100	.....
Italian State railways	.....	105	50.6
	.....	94	46.3
	.....	73	36.1
France:			
Eastern Railways	.....	94	46
Northern Railway	1900	92	.....
State Railways	.....	94	46.0
	.....	93	45.5
Paris, Lyon & Mediterranean Railways	1893	98	48
Belgium: State Railways	.....	82	39
	.....	116	57
Germany	1898	87	41.8
	1890	92	44.2
	1911	93.5	45
	1911	98.5	47.3
Austria: State Railways	1911	73	35
	1912	90	43
	1911	86	41.5
Holland: Netherlands Central Railway	1912	94	45.2
	1892	82	39.5
Sweden: State Railways	1896	83	40
	1899	70	33.6

It is very difficult to define in any way the severity of the service to which railway material is subjected, but some idea of it may be gained from a consideration of the dead weights and capacities of types of rolling stock.

In Table 3 is found a brief description of some types of foreign rolling stock. In some cases marked with an asterisk (*) the weights given are average values.

TABLE 3
Weights of Foreign Rolling Stock

Country	Locomotives		Passenger cars		Freight cars		
	Dead weight	Weight per axle	Dead weight	Weight per axle	Dead weight	Capacity	Maximum weight per axle
	Tons	Tons	Tons	Tons	Tons	Tons	Tons
United Kingdom	45–65	15–17	.....	.....	10–15	<*15	15
France	45–65	15–18	15	7	6–7	*13	.....
	[a] 50–92	11–18	36	8	10	15–18	15
	.....	.....	.....	.....	15–18	30–40	15
Germany	45–65	.....	.....	.....	10–15	*15.5	.....
Belgium	[a] 50–92	11–18	15	7	10	15–18	15
	.....	.....	36	8	15–18	30–40	15

[a] Ghent Exposition (1913).

A summary of the weights of axles and wheels is given in Table 4.

Often the size of the equipment, such as wheels or axles, is prescribed by setting an upper limit to the static stresses that may be developed in any part. For instance, the railroads of France prescribe generally, directly or indirectly, a maximum wheel load of from 16 100 to 16 800 pounds, while the German laws prescribe a maximum static stress of 10 000 pounds per square inch in the journal of freight-car axles and of 7900 pounds per square inch for passenger-car axles.

TABLE 4

Weights of Axles and Wheels, Freight and Passenger Cars

Country and railway	Date	Weight of axle		Date	Weight of wheel and tire	
		Pounds	Kilograms		Pounds	Kilograms
France: Eastern Railways	1912	564	254	1912	910	410
	1911	672	302	1911	910	410
	.....	764	345	1912	910	410
Austria: State Railways	.....	560	252	1911	910	410

3. RAILS

Specifications all call for steel rails, although chemically the kind of steel that is desired is generally not very definitely specified.

In the Table 5 is given a column showing what chemical specifications are in use, and it will be seen that in some cases even the carbon content is not specified. Certain characteristic items of the process of manufacture of rails are considered below with the various clauses concerning them.

Size of Ingot.—Several of the 12 sets of rail specifications give the size of the ingot from which the rails shall be rolled; these are those of the United Kingdom, the Italian State Railways, the Belgian State Railways, and the Holland Railway (Dutch).

Discard.—Most of the specifications call for a discard to be made after rolling. Those of the United Kingdom, the Northern Railway (France), the Paris, Lyon & Mediterranean Railways (France), the Belgian State Railways, and of the Holland Railway specify that enough discard be taken to insure soundness in the rail, while those of the Italian State Railways, the French State Railways, the Eastern Railways (France), and the Swedish State Railways require a definite amount of discard, which varies from 1.5 to 2.5 meters of the rail bar from the upper part of the ingot.

Gagging.—All of the specifications require that gradual application of the pressure be made in the process of cold straightening.

Finishing of the Rail Ends.—All of the specifications but those of the United Kingdom, the Swedish State Railways, and the Eastern and Northern Railways (French) state that the rail ends must be machine finished, milled or otherwise.

Tests and Taking of Test Specimens.—A synopsis is given in Table 5 showing what tests are required for rails and how many must be made for a given lot.

Ultimate strengths varying from 80 000 pounds per square inch to 112 000 pounds per square inch are called for, with elongations of from 15 to 8 per cent. In some cases the values for the ultimate strength and the elongation must stand in some prescribed relation. In only one case is the yield point specified.

The bending test required is a static one and generally consists of two parts. At first a span of the rail is loaded at the center with a load which is not supposed to permanently bend the rail. Thereupon a load is applied under which it yields, but only very slightly, the maximum amount of deflection at the center being prescribed.

The drop test is carried out with a drop testing machine, which consists of an anvil weighing 10 000 kg embedded in a mass of masonry 1 m deep and 3 m^2 in area. The weight of the tup varies from 600 to 2000 pounds when specified at all; its weight is not specified in the German, Austrian, and Dutch specifications. The British, Eastern Railways (French), Paris, Lyon & Mediterranean Railways (French), and the Belgian specifications call for one heavy blow, whereas the others, particularly those of the German group, call for numerous lighter blows.

TABLE 5

Synopsis of Rail Tests and Chemical Compositions Specified

Country and railway	Chemical elements specified	Tensile test	Bending test	Impact or drop test
United Kingdom (Engineering Standards Committee):				
Bull head	C, Mn, Si, P, S	1 per 100 tons		1 per 200 rails; 1 per heat.
Flat bottom	C, Mn, Si, P, S	do		Do.
Italy: State Railways.[a]	P, S	1 per group of 200 rails.[b]	1 per group of 200 rails.	1 per heat.

[a] Corrosion tests on specimens from every group of 200 rails are also prescribed.

[b] Here and elsewhere in this table the grouping is such that each group contains one or more heats.

TABLE 5—Continued

Country and railway	Chemical elements specified	Tensile test	Bending test	Impact or drop test
France:				
Eastern Railways.	.....	1 per group of 100 rails.	1 per group of 100 rails.	1 per group of 100 rails.
Northern Railway.	.....	.....do.....	.....do.....	1 preliminary test per heat; 1 per group of 100 rails.
State Railways.	C, P.....	1 per 200 rails	1 per 200 rails	1 preliminary test per heat; 1 per 200 rails.
Paris, Lyon & Mediterranean Railways.	C.....	3 per group of 300 tons.	3 per group of 300 tons.	1 preliminary test per heat; 3 per group of 300 tons.
Belgium: State Railways.	.....	1 per group of from 100 to 200 rails.	1 per group of from 100 to 200 rails.	1 per heat;[a] 1 per group of 100 to 200 rails.
Germany: Prussian-Hessian State Railways.[b]	.....	1 per group of 200 rails.	.....	1 per group of 200 rails.
Austria: State Railways.[b]	.....	.....do.....	1 per group of 200 rails.	Do.
Holland:				
North Brabant Railway.	.....	.....do.....	.....	Do.
Netherlands Central Railway.	.....	.....do.....	.....	Do.
Holland Railway.	.....	1 per group of 100 rails.	1 per group of 100 rails.	1 per group of 100 rails.
Sweden: State Railways.[b]	P.....	A tensile test is required.	.....	A drop test is required in each heat.

[a] This specimen is taken from upper end of ingot.
[b] A hardness (ball) test is required on 1 of every 200 rails.

4. AXLES

Axles are to be of steel, of which the chemical composition is not further specified, except that references are made to the phosphorus content and to the nickel content required for locomotive crank axles. Very often the cross section of the ingot from which the axle is forged is specified to be four or five times that of the finished axle. Usually axles are required to be annealed after forging, and locomotive axles quenched and drawn.

In the Table 6 is given a synopsis of the tests required for axles.

The tensile strength required varies from 64 000 pounds per square inch to 95 000 pounds per square inch and the elongation from 15 to 25 per cent. In a few cases the yield point is required to be from 40 to 50 per cent of the ultimate strength.

The drop test is carried out both on the body of the axle and on the journal; the weight of the hammer used is specified (2000

pounds) in only two or three cases. In all but one set of specifications several (5 to 8) blows are struck, and the axle is generally turned so that the blows are not all applied in the same direction.

In many cases a fracture test is required. For this purpose an axle of excess length is required, which is notched at one end and the excess length broken off in the drop testing machine. The fracture must be sound and homogeneous.

TABLE 6

Synopsis of Tests of Axles

Country and railway	Chemical elements specified	Tensile test	Drop test—journal	Drop test—body of axle	Miscellaneous tests
United Kingdom (Engineering Standards Committee).	S, P	1 per 50 [a]		1 per 50 [b]	
France:					
Eastern Railways	P [c]	do.[a]	1 per 50[a]	do.[a]	Fracture test on each axle.
Northern Railway	P [c]	do.[a]	do.[a]	do.[a]	Do.
Paris, Lyon & Mediterranean Railways.	P [c]	do.[a]	do.[a]	do.[a]	Do.
Belgium: State Railways		[a]		do	
Germany: Prussian Railways	[d]	1 per 50		do	
Austria: State Railways	P	1 per heat		1 per heat	
Holland:					
North Brabant Railway		do		do	
State Railways		1 per heat [a]		do	Bending test.[a]
Holland Railway	[d]	1 per 50			
Sweden: State Railways	[d]	2 per 50		1 per 50	

[a] For locomotive crank axles no tests on the whole axle are required, but from each axle small specimens are taken (from an excess length) upon which impact and tensile tests are carried out.

[b] This is a fatigue drop test for crank axles made on small specimens from axle and may have as an alternative a cold-bend test.

[c] The use of pig iron containing more than 0.1 per cent P is forbidden.

[d] Nickel or chromium content specified for crank axles.

5. WHEELS AND TIRES

Many types of car and locomotive wheels are used abroad. The chilled cast-iron wheel, the type most used in the United States for freight service, is not generally used, and is very seldom mentioned in foreign wheel specifications. It is allowed on German and Swedish railways for unbraked wheels on freight cars which run at limited speeds (45 km, or 28 miles, per hour). The type most generally used is a combination of wheel center of steel, cast or rolled, or wrought iron, with a shrunk-on steel tire. The wheel centers may be of the plate or of the ribbed or spoke type.

6. TIRES

The tires are to be of steel, forged and rolled into the desired shape. The Table 7 gives a synopsis of the tests required for tires.

TABLE 7

Synopsis of Tests of Tires

Country and railway	Chemical elements specified	Tensile test	Drop test	Hydraulic flattening test	Miscellaneous tests
United Kingdom (Engineering Standards Committee):					
Locomotive tires	P, S[a]	1 per 50 or 1 per heat.	1 per 50 or 1 per cast.		1 drop test on each tire.[b]
Passenger and freight-car tires.	P, S	1 per cast of 50.	1 per cast of 50.		Do.[b]
France: Eastern Railways[c]	P[d] 1 per heat.	1 per heat	1 per heat [e]	1 per heat.	
Belgium: State Railways		Required [f]	do.[g]	Required [f].	
Germany: Prussian State Railways.		1 per 50	1 per 50		
Austria: State Railways	P	1 per heat	1 per heat		
Holland:					
North Brabant Railway		do	do		
State Railways		1 per heat	do		
Holland Railway	P	do			
Sweden: State Railways		1 per 50	1 per 50		

[a] Also specified without analysis.
[b] The tire is let fall onto an anvil.
[c] The same data applies to the Paris, Lyon & Mediterranean.
[d] The use of pig iron containing more than 0.1 per cent is forbidden.
[e] For type (D) only.
[f] These are alternative to [g].
[g] See [f].

In the tensile test ultimate strengths are required, varying from 85 000 to 124 000 pounds per square inch, and elongations, from 8 to 18 per cent.

Two types of drop test are required. In the first, required in British specifications, each tire is dropped upon a rail fastened in an iron block. In the second type, required by all of the specifications, a fall hammer is used, the tire being supported on a block with its plane vertical. It is in some cases required merely that the tire not fracture or fissure under repeated blows of given energy, but in other cases (German and Austrian railways) it must be possible to flatten the tire by 12 per cent without any cracks appearing. The weight of the fall hammer is usually about 2000 pounds and the blows of about 20 000 foot-pounds of energy.

A static flattening test is also required in several cases. The amount by which the diameter of the tire is required to be reduced without failing is generally about 17 per cent.

7. WHEEL CENTERS

Wheel centers are made of forged steel, cast steel, or wrought iron. They are generally required to be annealed after being cast or forged.

The Table 8 gives a synopsis of the tests required for wheel centers for the various railways.

TABLE 8

Synopsis of Tests of Wheels

Country, railway, etc.	Material	Chemical elements specified	Bending test	Hub-expanding test	Equilibrium test	Tensile test	Drop test	Miscellaneous test
United Kingdom: Engineering Standards Committee.[b]	Cast steel	P. S.				1 per heat	Each wheel center.[c]	1 bending test[a] from each wheel center.
France:								
Eastern Railways—								
Plate wheel centers	Wrought iron	P	1 per 100 W	1 per 100 W	Each wheel			
	Steel	1 analysis per heat.						
Cast wheel centers	Cast steel	P[d]	do	do.[e]	do.[e]	1 per heat	1 per heat	
Northern Railways [f]—								
Plate wheel centers	Wrought iron	P	do	do	do			
	Steel	1 analysis per heat.						
Ribbed, spoked wheels	Wrought iron		do	do	do			Weldability, quench, and bending on small specimens.[g]
	Steel							
Cast wheel centers	Cast steel	(d)	do	do.[e]	do.[e]	1 per heat	1 per heat	
Belgium: State Railways	Wrought iron							
	Cast steel				Required	Tensile test is required.		
Germany: Prussian State Railways	Cast steel			1 per 50		1 per 50		
	Soft steel			do		do		
	Wrought iron				Required	1 per 50 W		
Austria: State Railways	Cast steel	1 analysis per heat.			Each pair	2 per heat	Each wheel [b]	
	Forged soft steel.				do	Required (1 per heat).	1 per heat	

Holland:								
North Brabant Railway [h]	Cast steel							
	Soft steel							
State Railways	Wrought iron						Required	
Holland Railway	Cast steel				1 per 50 W	Each pair	3 per 50 W	
Sweden: State Railways	Steel					do	1 per 100 W	1 per 100 W.

[a] This bending test is made on a small cast on specimen and not on the whole wheel center.
[b] A "ringing" test is required.
[c] The wheel center is dropped upon an anvil.
[d] The pig iron may contain not more than 0.1 per cent P.
[e] For simple wheels only.
[f] The data here shown apply also to the State Railways and the Paris, Lyon & Mediterranean Railways.
[g] For steel wheels only.
[h] Same data apply also to the Netherlands Central Railway.

In the tensile test values of the ultimate strength are required varying from 52 000 to 91 000 pounds per square inch and values of the elongation from 15 to 20 per cent.

Each wheel center must be equilibrated, and a limit is set upon the amount of variation from the state of being perfectly centered.

In the transverse bending test the wheel center is supported flat at the rim, and pressure is applied at the hub parallel to the axis of the wheel; the wheel must allow of the hub being lowered by about 4 per cent of the diameter of the wheel rim.

In the hub-expanding test mandrels with a 1/100 taper or greater are introduced into the bore of the hub until one end has been expanded by about 5 per cent. This test must be passed without any fissuring at the hub.

There are two types of drop test applied; in one the wheel center itself is dropped upon an anvil; in the other, which is carried out on test pieces from the wheel center, a fall hammer is used.

The Austrian specifications require that the bending test be made by impact.

8. GUARANTIES FOR MATERIALS

Service guaranties are required in several specifications for all of these materials. For example, rails are often required to be guaranteed against failure, which can be considered as due to the manufacture or material for a period of six years. Table 9, giving a summary of these guaranties required, is shown below:

TABLE 9

Summary of Service Guaranties Required on Wheels, Axles, Tires, and Rails

Country and railway	Rails	Axles		Tires	Wheels
		Kilometers	Miles		
France:	Years			Years	Years
Eastern Railways	6				
Northern Railway	6	[a] 80 000 [b] 50 000 [c] 100 000	50 000 31 000 62 000		
Belgium		(d)	(d)	3	2
Germany	5				[e] 3
Austria	5				4
Holland	5	[f] 165 000	103 000	3	3

[a] For carriages and cars.
[b] In a period of 3 years.
[c] In a period of 4 years.
[d] Axles guaranteed for a period of 3 years.
[e] Applies tof reight cars.
[f] For crank axles.

9. CONCLUSION

In conclusion, a few points of general practice may be touched upon.

It is noticed that almost without exception the foreign specifications cited rely upon physical tests alone rather than upon chemical analyses or both chemical analysis and physical tests for their information concerning the various materials. Only phosphorus and occasionally sulphur seem to have engaged the attention of those drawing up the specifications. The physical tests always include stringent toughness or brittleness tests, which of course somewhat lessen the necessity of chemical analyses.

The specifications generally require that the manufacture of the articles and materials be under the surveillance of the inspecting agents and that the latter must have free access to the shops and plants of the manufacturers at all times during the manufacture of the articles in question.[6]

The practice in regard to indicating the method of manufacture is not uniform. In some cases (e. g., in Germany) this is almost entirely left to the manufacturer, who must, however, state in his bids what method will be used. In many cases open-hearth steel is specified, particularly for axles; in others both Bessemer and open-hearth material is allowed, as, for example, rails. In some cases nothing is mentioned regarding the method of manufacture of the material.

In most cases the mode of manufacture of the article is given in general details. For example, it may be specified that a wheel center shall be of cast steel, or of forged or rolled steel, afterwards annealed.

WASHINGTON, June 17, 1915.

[6] Such clauses are often found not in the particular specifications relating to the several articles, but in general ones of general applicability—e. g., Austrian specifications.

APPENDIX

SPECIFICATIONS FOR RAILWAY MATERIAL

[NOTE.—In the following specifications there have been some differences of practice with respect to omissions of the original texts.

If a specification is not marked with the asterisk (*) or with the dagger (†), it signifies that this specification is reproduced in full except where omission is noted in parenthesis with reference to the subject of the clauses of which omission was made.

A specification or set of regulations marked with the asterisk (*) is not in general fully reproduced; only those features have been selected which are of interest for the present purpose, and the text is in many cases paraphrased.

Specifications marked with the dagger (†) are complete as far as concerns the articles with which the present paper is concerned, namely, rails, axles, wheels, and tires, but clauses dealing wholly with other articles are omitted without mention being made of the omission.

The Bureau will be glad to fill in omissions in the specifications to interested parties by correspondence.]

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UNITED KINGDOM

ENGINEERING STANDARDS COMMITTEE

BRITISH STANDARD SPECIFICATION AND SECTIONS OF FLAT-BOTTOM RAILWAY RAILS (REVISED JULY, 1909)

1. Chemical Composition.—The steel for the rails shall be of the best quality made by the Bessemer, Siemens-Martin, or other process, as may be approved by the engineer (or by the purchaser).

The rails shall show on analysis that in chemical composition they conform to the following limits:

Carbon, from 0.35 to 0.50 per cent.
Manganese, from 0.70 to 1 per cent.
Silicon not to exceed 0.10 per cent.
Phosphorus not to exceed 0.07 per cent.
Sulphur not to exceed 0.07 per cent.

2. Chemical Analysis.—The manufacturer shall make and furnish to the representative of the engineer (or of the purchaser) carbon and phosphorus determinations of each cast.

A complete chemical analysis, representing the average of the other elements contained in the steel, shall be similarly given for each rolling. Such complete analysis shall be made from drillings taken from the rail or from the tensile test piece or pieces. When the rolling exceeds 200 tons, an additional complete analysis shall be made for each 200 tons or part thereof.

Should the engineer (or the purchaser) desire to make independent chemical determinations, the necessary specimens and samples shall be furnished by the manufacturer. For this purpose not more than two rails in every 100 tons manufactured shall be selected by the representative of the engineer (or of the purchaser) and drillings taken with a drill of 2 inches diameter from the top of the head of the rail unless otherwise specified by him; and if, upon being subjected to the specified tests, either fail to comply therewith, then all the rails in the cast of which the test pieces form a part may be rejected.

The representative of the engineer (or of the purchaser) may then take similar samples from a further two rails out of the same 100 tons, and should either fail to comply with the specified analysis the whole 100 tons may be rejected.

In case of difference between the engineer (or between the purchaser) and the manufacturer as to the accuracy of an analysis, either party shall have the right to have samples of the steel analyzed by an independent metallurgist, to be mutually agreed upon. The expenses attendant upon such independent analysis shall be borne by the party adjudged to be in the wrong.

3. Manufacture.—Each rail shall be made from an ingot not less than 12 inches square at the smaller end and 14 inches square at the larger end, which must be cogged down into blooms, and have sufficient crop then sheared from each end to insure soundness.

All straightening shall be done by pressure and not by hammering.

4. Permissible Variation in Weight.—A rolling margin of one-half per cent under to one-half per cent above the calculated weight will be permitted, but the calculated weight only will be paid for.

6. Templates.—Before the general manufacture of the rails is commenced the manufacturer shall, if required by the engineer (or by the purchaser), supply two sets of templates, internal and external, of approved material, for each "B. S." section of rail.

Each template shall be suitably engraved with the purchaser's name, the number of the "B. S." section (being the nominal weight of the rail in pounds per yard), the manufacturer's name and address, and the date of the contract.

These templates shall be submitted to the engineer (or to the purchaser) for his approval, and at the commencement of rolling the engineer will have a competent person present to approve of the section.

7. Rails to Conform to Templates.—Each section of rail shall be accurately rolled to its respective template.

8. Rails to be Free from Defects.—The whole of the rails shall be of uniform section throughout, true to templates, perfectly sound and straight, and free from splits, cracks, burrs, and defects of every kind.

9. Length of Rails for Straight Line.—A quantity of short lengths will be taken in such lengths and quantities as may be ordered by the engineer (or by the purchaser), provided that these short lengths are cut down from longer lengths found to be defective at the ends only, and that the total quantity taken does not exceed 7½ per cent of the contract.

10. Permissible Variation in Length.—The rails shall be the specified length at a temperature of 60° F. No rail will be accepted which is more than three-sixteenths of an inch above or below the length specified, whether for straight or curved lines.

11. Rails of Special Length for Matching in Curved Line.—When required by the engineer (or by the purchaser) rails are to be supplied from 1 to 6 inches shorter or longer than the normal specified lengths, and these special lengths are to have about 1 foot at each end painted with such colors as may be ordered.

13. Branding.—The brand shall be rolled on the web of each rail to show that the rail is of British standard section and made under the conditions of this specification; the number of the "B. S." section (being the nominal weight of the rail in pounds per yard), the process [7] by which the rails have been manufactured, the manufacturer's name, initials, or other recognized mark, and the month and year of manufacture shall also be rolled, in letters three-quarters of an inch in size, on one side of the web of each rail—e. g., B. S. 95- B. A.[7] ..... 4.04—and the number of the cast from which it has been rolled shall be stamped on the end of each rail in half-inch block figures.

14. Impact Test.—From each cast a piece of rail (which may be a crop end) shall be selected by the representative of the engineer (or of the purchaser) and stamped with his mark and the number of the cast. From this a piece 5 feet long shall be cut which shall be placed in a horizontal position, with the head uppermost, upon two iron or steel supports resting on a solid foundation, the upper surfaces of the supports being curved to a radius of 3 inches. The test shall comprise one blow, delivered midway between the bearings, from a falling iron weight or tup, the striking face of which shall be rounded to a radius of not more than 5 inches. The weight of the tup, the span of the test piece between the centers of the bearings, and the height of the drop for the various sections of rails shall be as tabulated below. The blow must be sustained without fracture. In addition to the above test the representative of the engineer (or of the purchaser) shall select one finished rail from every 200 offered, and a piece 5 feet in length cut from this rail shall be similarly tested as specified above.

[7] The following abbreviations are recommended: S. A., Siemens-Martin acid; S. B., Siemens-Martin basic; B. A., Bessemer acid; B. B., Bessemer basic.

B. S. section and nominal weight of rails per yard in pounds	Falling weight test		
	Weight of tup	Centers of bearings	Drop
	Cwts	Feet	Feet
20	5	3	8
25	5	3	9
30	10	3	10
35	10	3	12½
40	10	3	15
45	15	3	15
50	15	3	15
55	15	3	17½
60	20	3	20
65	20	3	20
70	20	3½	20
75	20	3½	20
80	20	3½	22
85	20	3½	24
90	20	3½	26
95	20	3½	28
100	20	3½	30

Should the length cut from the selected rail fail to comply with the test specified for its weight, two other rails from the same cast will be selected and similar lengths cut and tested, and the acceptance or rejection of the cast will be decided by the result of the three tests, so that if two of the rails selected fail to comply with the test the entire cast will be rejected.

15. Tensile Test.—From each 100 tons of rails the manufacturer shall (if required by the representative of the engineer or of the purchaser) cut a test piece from any rail selected as a sample rail, such test piece to be stamped to correspond with the sample rail. It shall then be placed in a testing machine of approved pattern, and shall have an ultimate tensile strength of not less than 40 tons per square inch nor more than 48 tons per square inch, with an elongation of not less than 15 per cent upon the standard test pieces C or D (see sketch, p. 47). Should the test piece fail to fulfill these conditions, the representative of the engineer (or of the purchaser) may require the manufacturer to test two other rails from the same cast in the same manner, and the acceptance or rejection of the cast shall be decided by the result of the three tests, so that if two of the three rails selected fail to comply with the test the entire cast will be rejected.

The representative of the engineer (or of the purchaser) may then take similar test pieces from a further two rails out of the same 100 tons, and should either fail to comply with the test the whole 100 tons may be rejected.

Should the engineer (or the purchaser) desire to have independent tests made, the manufacturer shall provide the necessary test pieces, viz, two for every 200 tons, properly shaped and prepared.

16. Holes in Rails.—The holes for fishbolts shall be drilled through the web from the solid at each end of the rails of the sizes and in the position shown in the British standard specification for fishplates for flat-bottom rails or on a drawing to be supplied by the engineer (or by the purchaser). These holes must be clean and square with the web, without burrs on either side, and will be checked with the gauges to be furnished to the manufacturer by the engineer (or by the purchaser). Should any of the holes vary from the correct size or position more than one thirty-second of an inch, the rails in question will be liable to rejection.

17. Notice of Rolling to be Given.—The manufacturer shall give to the engineer (or to the purchaser) or his representative at least seven clear days' previous notice, in writing, before the rolling of the first lot of rails, and at least three clear days' previous notice, in writing, before the rolling of any subsequent lot of rails is commenced, in order that arrangements may be made for the presence of the representative of the engineer (or of the purchaser) at the rolling.

18. Inspection and Testing.—The engineer (or the purchaser) or his representative shall have free access to the works of the manufacturer at all reasonable times; he shall be at liberty to examine the rails during any stage of their manufacture, and to reject any material or finished rail which does not conform to the terms of this specification.

Before the rails are put before the representative of the engineer (or of the purchaser) for inspection the manufacturer shall have them examined, and all rails which he admits to be defective shall be sorted out and placed in a separate stack, the representative of the engineer (or of the purchaser) being empowered to refuse to inspect any lot of rails not put in uniform lengths and sorted.

19. Testing Facilities.—The manufacturer shall supply the material required for testing free of charge and shall, at his own cost, furnish and prepare the necessary test pieces, and supply labor and appliances for such testing as may be carried out on his premises in accordance with this specification. Failing facilities at his own works for making the prescribed tests, the manufacturer shall bear the cost of carrying out the tests elsewhere.

20. Marking of Accepted Rails.—All rails accepted by the representative of the engineer (or of the purchaser) shall be stamped in his presence.

BRITISH STANDARD SPECIFICATION AND SECTIONS OF BULL HEAD RAILWAY RAILS (REVISED JULY, 1909)

1. Chemical Composition.—The steel for the rails shall be of the best quality made by the Bessemer, Siemens-Martin, or other process, as may be approved by the engineer (or by the purchaser).

The rails shall show on analysis that in chemical composition they conform to the following limits:

Carbon, from 0.35 to 0.50 per cent.
Manganese, from 0.70 to 1 per cent.
Silicon, not to exceed 0.10 per cent.
Phosphorus, not to exceed 0.075 per cent.
Sulphur, not to exceed 0.08 per cent.

2. Chemical Analysis.—The manufacturer shall make and furnish to the representative of the engineer (or of the purchaser) carbon determinations of each cast.

A complete chemical analysis, representing the average of the other elements contained in the steel, shall be similarly given for each rolling. Such complete analysis shall be made from drillings taken from the rail or from the tensile test piece or pieces. When the rolling exceeds 200 tons, an additional complete analysis shall be made for each 200 tons or part thereof.

Should the engineer (or the purchaser) desire to make independent chemical determinations, the necessary specimens and samples shall be furnished by the manufacturer. For this purpose not more than two rails in every 100 tons manufactured shall be selected by the representative of the engineer (or of the purchaser) and drillings taken with a drill of 2 inches diameter from the top of the head of the rail, unless otherwise specified by him; and if, upon being subjected to the specified tests, either fail to comply therewith, then all the rails in the cast of which the test pieces form a part may be rejected.

The representative of the engineer (or of the purchaser) may then take similar samples from a further two rails out of the same 100 tons, and should either fail to comply with the specified analysis the whole 100 tons may be rejected. In case

of difference between the engineer (or between the purchaser) and the manufacturer as to the accuracy of an analysis, either party shall have the right to have samples of the steel analyzed by an independent metallurgist, to be mutually agreed upon. The expenses attendant upon such independent analysis shall be borne by the party adjudged to be in the wrong.

3. **Manufacture.**—Each rail shall be made from an ingot not less than 12 inches square at the smaller end and 14 inches square at the larger end, which must be cogged down into blooms, and have sufficient crop then sheared from each end to insure soundness.

All straightening shall be done by pressure and not by hammering.

4. **Permissible Variation in Weight.**—A rolling margin of one-half per cent under to one-half per cent above the calculated weight will be permitted, but the calculated weight only will be paid for.

6. **Templates.**—Before the general manufacture of the rails is commenced the manufacturer shall, if required by the engineer (or by the purchaser), supply two sets of templates, internal and external, of approved material, for each B. S. section of rail.

Each template shall be suitably engraved with the purchaser's name, the number of the B. S. section (being the nominal weight of the rail in pounds per yard), the manufacturer's name and address, and the date of the contract.

These templates shall be submitted to the engineer (or to the purchaser) for his approval, and at the commencement of rolling the engineer will have a competent person present to approve of the section.

7. **Rails to Conform to Template.**—Each section of rail shall be accurately rolled to its respective template.

8. **Rails to be Free from Defects.**—The whole of the rails shall be of uniform section throughout, true to templates, perfectly sound and straight, and free from splits, cracks, burrs, and defects of every kind.

9. **Length of Rails for Straight Line.**—A quantity of short lengths will be taken in such lengths and quantities as may be ordered by the engineer (or by the purchaser), provided that these short lengths are cut down from longer lengths found to be defective at the ends only, and that the total quantity taken does not exceed 7½ per cent of the contract.

(N. B.—The committee recommend the adoption of the following as the normal lengths of rails, viz: 30 feet, 36 feet, 45 feet, or 60 feet.)

10. **Permissible Variation in Length.**—The rails shall be the specified length at a temperature of 60° F. No rail will be accepted which is more than three-sixteenths of an inch above or below the length specified, whether for straight or curved line.

11. **Rails of Special Length for Matching in Curved Line.**—When required by the engineer (or by the purchaser), rails are to be supplied from 1 to 6 inches shorter or longer than the normal specified lengths, and these special lengths are to have about 1 foot at each end painted with such colors as may be ordered.

12. **Rails for Switches and Crossings.**—Rails shall be supplied for switches and crossings when so ordered and such rails shall be of the required lengths and shall be cut from sound rails.

13. **Branding.**—The brand shall be rolled on the web of each rail to show that the rail is of British standard section and made under the conditions of this specification; the number of the B. S. section (being the nominal weight of the rail in pounds per yard), the process [8] by which the rails have been manufactured, the manufacturer's name, initials, or other recognized mark, and the month and year of manufacture shall be rolled, in letters three-quarters of an inch in size, on one side of the web of each rail—e. g., B. S. 95-B. A.,[8] ..... 4.01—and the number of the cast from which it has been rolled shall be stamped on the end of each rail in half-inch block figures.

[8] The following abbreviations are recommended: S. A., Siemens-Martin acid; S. B., Siemens-Martin basic; B. A., Bessemer acid; B. B., Bessemer basic.

14. Impact Test.—From each cast one rail shall be selected by the representative of the engineer (or of the purchaser). From this a piece 5 feet long shall be cut which shall be placed in a horizontal position with the bull head uppermost upon two iron or steel supports resting on a solid foundation, and placed so that their centers are 3 feet 6 inches apart, the upper surfaces of the supports being curved to a radius of 3 inches. The test shall comprise two blows delivered midway between the bearings from a falling iron weight of 2240 pounds, the striking face of which shall be rounded to a radius of not more than 5 inches. The height of drop for the various sections of rails shall be as tabulated below. The blows must be sustained without fracture and the rail must show a deflection between the limits given below.

B. S. section and nominal weight of rails per yard in pounds	Falling weight test					
	First blow			Second blow		
	Drop	Deflection		Drop	Deflection	
		From	To		From	To
	Feet	Inch	Inches	Feet	Inches	Inches
60	5	1	$1\frac{5}{16}$	10	3	$3\frac{3}{4}$
65	5	1	$1\frac{1}{4}$	12	3	$3\frac{3}{4}$
70	6	1	$1\frac{5}{16}$	12	3	$3\frac{3}{4}$
75	6	1	$1\frac{5}{16}$	12	3	$3\frac{3}{4}$
80	6	$\frac{7}{8}$	$1\frac{3}{16}$	15	3	4
85	6	$\frac{7}{8}$	$1\frac{3}{16}$	15	3	4
90	7	$\frac{7}{8}$	$1\frac{1}{4}$	20	3	$4\frac{1}{4}$
95	7	$\frac{7}{8}$	$1\frac{3}{16}$	20	3	$4\frac{1}{4}$
100	7	$\frac{7}{8}$	$1\frac{3}{16}$	20	3	$4\frac{1}{4}$

Should the length cut from the selected rail fail to comply with the test specified for its weight, two other rails from the same cast will be selected and similar lengths cut and tested, and the acceptance or rejection of the cast will be decided by the result of the three tests, so that if two of the rails selected fail to comply with the test the entire cast will be rejected.

15. Tensile Test.—From each 100 tons of rails the manufacturer shall (if required by the representative of the engineer or of the purchaser) cut a test piece from any rail selected as a sample rail, such test piece to be stamped to correspond with the sample rail. It shall then be placed in a testing machine of approved pattern, and shall have an ultimate tensile strength of not less than 40 tons per square inch, nor more than 48 tons per square inch, with an elongation of not less than 15 per cent upon the standard test pieces C or D. (See sketch p. 47.) Should the test piece fail to fulfill these conditions, the representative of the engineer (or of the purchaser) may require the manufacturer to test two other rails from the same cast in the same manner, and the acceptance or rejection of the cast shall be decided by the result of the three tests, so that if two of the three rails selected fail to comply with the test the entire cast will be rejected.

The representative of the engineer (or of the purchaser) may then take similar test pieces from a further two rails out of the same 100 tons and should either fail to comply with the test the whole 100 tons may be rejected.

Should the engineer (or the purchaser) desire to have independent tests made, the manufacturer shall provide the necessary test pieces, viz, two for every 200 tons, properly shaped and prepared.

16. Holes in Rails.—The holes for fishbolts shall be drilled through the web from the solid at each end of the rails, of the sizes and in the position shown in the British

standard specification for fishplates for bull head rails, or on a drawing to be supplied by the engineer (or by the purchaser). These holes must be clean and square with the web, without burrs on either side, and will be checked with the gauges to be furnished to the manufacturer by the engineer (or by the purchaser). Should any of the holes vary from the correct size or position more than one thirty-second of an inch the rails in question will be liable to rejection.

17. Notice of Rolling to be Given.—The manufacturer shall give to the engineer (or to the purchaser), or his representative, at least seven clear days' previous notice, in writing, before the rolling of the first lot of rails, and at least three clear days' previous notice, in writing, before the rolling of any subsequent lot of rails is commenced, in order that arrangements may be made for the presence of the representative of the engineer (or of the purchaser) at the rolling.

18. Inspection and Testing.—The engineer (or the purchaser) or his representative shall have access to the works of the manufacturer at all reasonable times; he shall be at liberty to examine the rails during any stage of their manufacture and to reject any material or finished rail which does not conform to the terms of this specification.

Before the rails are put before the representative of the engineer (or of the purchaser) for inspection the manufacturer shall have them examined, and all rails which he admits to be defective shall be sorted out and placed in a separate stack, the representative of the engineer (or of the purchaser) being empowered to refuse to inspect any lot of rails not put in uniform lengths and sorted.

19. Testing Facilities.—The manufacturer shall supply the material required for testing free of charge and shall, at his own cost, furnish and prepare the necessary test pieces and supply labor and appliances for such testing as may be carried out on his premises in accordance with this specification. Failing facilities at his own works for making the prescribed tests, the manufacturer shall bear the cost of carrying out the tests elsewhere.

20. Marking of Accepted Rails.—All rails accepted by the representative of the engineer (or of the purchaser) shall be stamped in his presence.

BRITISH STANDARD SPECIFICATION FOR LOCOMOTIVE CRANK AXLES (WITH ANALYSIS)

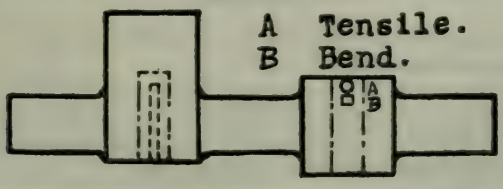
1. Quality of Material.—The crank axles shall be manufactured from the highest quality of steel made from the best selected material by the acid open-hearth process and must not show on analysis more than 0.035 per cent of sulphur or of phosphorus.

The manufacturer shall supply an analysis when required to do so.

2. Freedom from Defects.—The crank axles must be free from defects of any kind and accurately finished to the prescribed dimensions.

3. Branding.—The crank axles shall be distinctly stamped, when hot, on the web nearest the top of the ingot with such brands as the engineer (or the purchaser) may require.

4. Test Pieces.—Crank Axles Having Flat or Oval Webs.—Test pieces shall be machined cold from between each pair of webs of each crank axle and taken in the direction indicated in the sketch. The cranks shall be slotted or sawn.



Crank Axles Having Round Webs.—Test pieces shall be taken from pieces forged on each end of each crank axle and having the same diameter as the wheel seat.

In either case the test pieces shall not be detached from the axles until stamped by the representative of the engineer (or of the purchaser).

5. **Mechanical Tests.**—Test pieces machined from the axles as above must withstand the following tests without further reheating or any other manipulation whatever.

6. **Tensile Test.**—A standard test piece C or D (see sketch p. 47) must show a tensile breaking strength of not less than 30 tons per square inch, with an elongation of not less than 25 per cent, or if the crank axle be oil treated not less than 35 tons per square inch, with an elongation of not less than 20 per cent. The yield point[9] in either case must be not less than 50 per cent of the ultimate tensile strength.

7. **Number of Tensile Tests.**—CRANK AXLES HAVING FLAT OR OVAL WEBS.—One tensile test shall be taken from between each pair of webs of each crank axle.

CRANK AXLES HAVING ROUND WEBS.—One tensile test shall be taken from each end of each crank axle.

8. **Cold-Bend Test.**—A test piece 9 inches long, 1¼ inches square, with one-sixteenth inch radius at the edges, machined from the crank axles, as in clause 5, must withstand being bent cold through an angle of 90° around a bar 2½ inches diameter, and the test continued after the bar is removed by the ends being brought together without fracture.

9. **Number of Cold-Bend Tests.**—CRANK AXLES HAVING FLAT OR OVAL WEBS.—One cold-bend test shall be taken from between each pair of webs of each crank axle.

CRANK AXLES HAVING ROUND WEBS.—One cold-bend test shall be taken from each end of each crank axle.

10. **Fatigue Test.**—As an alternative to the cold-bend test, the test piece referred to in clause 8 may be placed upon bearings having a clear span of 6 inches, resting on a solid foundation, and must withstand without fracture 20 blows from a weight of 1120 pounds, having a rounded end of 1¼ inches radius, falling 6 inches. The test piece shall be reversed after the first and every alternate blow. The fall shall then be increased 12 inches and the test continued until fracture occurs.

11. **Reheating or Oil Treating.**—All crank axles shall be either reheated or oil treated.

12. **Inspection.**—The representative of the engineer (or of the purchaser) shall have free access to the works of the manufacturer at all reasonable times; he shall be at liberty to inspect the manufacture at any stage and to reject any material that does not conform to the terms of this specification.

13. **Testing Facilities.**—The manufacturer shall supply the material required for testing free of charge and shall, at his own cost, furnish and prepare the necessary test pieces and supply labor and appliances for such testing as may be carried out on his premises in accordance with this specification. Failing facilities at his own works for making the prescribed tests, the manufacturer shall bear the cost of carrying out the tests elsewhere.

BRITISH STANDARD SPECIFICATION FOR LOCOMOTIVE CRANK AXLES (WITHOUT ANALYSIS)

These specifications are identical with the preceding, except that in paragraph 1 no chemical analysis is specified.

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[9] The yield point shall, for the purpose of this specification, be the load per square inch at which a distinctly visible increase occurs in the distance between gauge points on the test piece, observed by using dividers; or at which when the load is increased at a moderately fast rate there is a distinct drop of the testing-machine lever, or, in hydraulic machines, of the gauge finger.

BRITISH STANDARD SPECIFICATION FOR LOCOMOTIVE STRAIGHT AXLES (WITH ANALYSIS)

1. Quality of Material.—The axles shall be manufactured from the highest quality of steel made from the best selected material by the acid open-hearth process and must not show on analysis more than 0.035 per cent of sulphur or of phosphorus.

The manufacturer shall supply an analysis when required to do so.

2. Freedom from Defects.—The axles must be free from defects of any kind and accurately finished to the prescribed dimensions.

3. Branding.—The axles shall be distinctly stamped when hot, as far from the center as practicable, with such brands as the engineer (or the purchaser) may require and in such a manner that these marks shall be legible when the axles are worn out. When axles are machined the brands shall be restamped cold on one end.

4. Mechanical Tests.—Extra axles for testing in the manner described in clauses 5, 6, or 7 shall be provided by the manufacturer, at his own expense, at the rate of 2 per cent of the axles ordered under the contract, but, except as provided below, one extra axle shall be provided from each cast, and the representative of the engineer (or of the purchaser) shall select and test such of the axles as he may think proper to the extent of such percentage or extra number. The axles tested shall be held to represent correctly the quality of the casts from which they were made. In the case of a less number than 15 axles being asked for under the contract, or less than 15 being made from each cast, the manufacturer may either (1) provide an extra axle for testing, or (2) leave a piece on each axle of the same diameter as the forged end of the axle to enable the representative of the engineer (or of the purchaser) to stamp one such piece from which test pieces may be cut for the tensile test and cold-bend test specified in clauses 6 and 7. After selection of axles for testing, each test axle must comply with the following tests without further reheating or any other manipulation whatever either of the axle selected for testing or of any portion cut therefrom to furnish test pieces.

5. Falling-Weight Test.—The axle shall be placed upon bearings resting on a block of metal of not less than 5 tons weight supported on a rigid concrete or other solid foundation and must withstand, without fracture, five blows from a falling weight of 2240 pounds, as specified below.

The axle shall be turned after the first and third blow and shall be broken after testing, both in the center and at the journals.

Diameter of axle at center	Number of blows	Height of fall	Distance between points of support [10]
		Feet	Ft. In.
Under 4 inches	5	16	3 0
4 inches and under 4¼ inches	5	18	3 6
4¼ inches and under 4½ inches	5	20	3 6
4½ inches and under 4¾ inches	5	22	3 6
4¾ inches and under 5 inches	5	24	3 6
5 inches and under 5¼ inches	5	24	4 0
5¼ inches and under 5½ inches	5	28	4 0
5½ inches and under 5¾ inches	5	28	4 6
5¾ inches and under 6 inches	5	32	4 6
6 inches and over	5	35	5 0

[10] In cases where the length of the axle does not permit of these distances being adhered to the distance between the points of support shall be as great as possible.

6. **Tensile Test.**—A standard test piece C or D (see sketch, p. 47), machined cold from one end of each axle tested as above, must show a tensile breaking strength of 35 to 40 tons per square inch, with an elongation of not less than 25 per cent with 35 tons and 20 per cent with 40 tons, the sums of the intermediate tensile breaking strengths and corresponding elongations being not less than 60. The yield point [11] must be not less than 50 per cent of the ultimate tensile strength.

7. **Cold-Bend Test.**—A test piece 9 inches long and 1¼ inches square, with one-sixteenth inch radius at the edges, must withstand being bent cold through an angle of 90° around a bar 2½ inches diameter, and the test continued, after the bar is removed, by the ends being brought together without fracture.

(N. B.—This test will be taken only when a less number than 15 axles are ordered and the falling-weight test (clause 5) has not been carried out.)

8. **Additional Tests Before Rejection.**—In the event of the axle selected for testing not satisfying the requirements of the tensile or bend tests, and the fractured test piece indicating that the result does not fairly represent the bulk of the axles, the representative of the engineer (or of the purchaser) may, at his discretion, and at the expense of the manufacturer, take two more test pieces from the same axle for repeating the test under which failure occurred. The axles will be accepted if the results of the repeat tests are satisfactory.

Should the axle fail in the falling-weight test, the cast which the axle represents shall be rejected.

9. **Independent Tests.**—If the engineer (or the purchaser) desires to make independent tensile or other tests of the material, the broken pieces of any of the axles tested shall be placed at his disposal for the purpose, free of charge.

10. **Reheating or Oil Treating.**—All axles shall be either reheated or oil treated.

11. **Inspection.**—The representative of the engineer (or of the purchaser) shall have free access to the works of the manufacturer at all reasonable times; he shall be at liberty to inspect the manufacture at any stage and to reject any material that does not conform to the terms of this specification.

12. **Testing Facilities.**—The manufacturer shall supply the material required for testing free of charge and shall, at his own cost, furnish and prepare the necessary test pieces, and supply labor and appliances for such testing as may be carried out on his premises in accordance with this specification. Failing facilities at his own works for making the prescribed tests, the manufacturer shall bear the cost of carrying out the tests elsewhere.

BRITISH STANDARD SPECIFICATION FOR LOCOMOTIVE STRAIGHT AXLES (WITHOUT ANALYSIS)

These specifications are identical with the preceding, except that in paragraph 1 no chemical analysis is specified.

BRITISH STANDARD SPECIFICATION FOR CAR [11a] AXLES (WITH ANALYSIS)

1. **Quality of Material.**—The axles shall be manufactured from the highest quality of steel made from the best selected material by the acid open-hearth process and must not show on analysis more than 0.035 per cent of sulphur or of phosphorus.

The manufacturer shall supply an analysis when required to do so.

2. **Freedom from Defects.**—The axles must be free from defects of any kind and accurately finished to the prescribed dimensions.

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[11] The yield point shall, for the purpose of this specification, be the load per square inch at which a distinctly visible increase occurs in the distance between the gauge points on the test piece, observed by using dividers; or at which when the load is increased at a moderately fast rate there is a distinct drop of the testing machine lever, or, in hydraulic machines, of the gauge finger.

[11a] In the original specifications the terms "carriage and waggon" were used in the sense of passenger and freight car, respectively.

3. Branding.—The axles shall be distinctly stamped when hot, as far from the center as practicable, with such brands as the engineer (or the purchaser) may require and in such a manner that these marks shall be legible when the axles are worn out. When axles are machined the brands shall be restamped cold on one end.

4. Mechanical Tests.—Extra axles for testing in the manner described in clauses 5, 6, or 7 shall be provided by the manufacturer, at his own expense, at the rate of 2 per cent of the axles ordered under the contract, but, except as provided below, one extra axle shall be provided from each cast of 50, or two axles when a cast consists of more than 50, and the representative of the engineer (or of the purchaser) shall select and test such of the axles as he may think proper to the extent of such percentage or extra number. The axles tested shall be held to represent correctly the quality of the casts from which they were made. In the case of a less number than 15 axles being asked for under the contract, or less than 15 being made from each cast, the manufacturer may either (1) provide an extra axle for testing, or (2) leave a piece on each axle of the same diameter as the forged end of the axle, to enable the representative of the engineer (or of the purchaser) to stamp one such piece from which test pieces may be cut for the tensile test and cold-bend test specified in clauses 6 and 7. After selection of axles for testing, each test axle must comply with the following tests without further reheating or any other manipulation whatever, either of the axles selected for testing or of any portion cut therefrom to furnish the test pieces.

5. Falling-Weight Test.—The axle shall be placed upon bearings resting on a block of metal of not less than 5 tons weight supported on a rigid concrete or other solid foundation, and must withstand, without fracture, five blows from a falling weight of 2240 pounds, as specified below.

The axle shall be turned after the first and third blow and shall be broken in the center after testing.

Diameter of axle at center	Number of blows	Height of fall	Distance between points of support [12]
		Feet	Ft ins
Under 3¼ inches	5	15	3 0
3¼ inches and under 4 inches	5	16	3 0
4 inches and under 4¼ inches	5	18	3 6
4¼ inches and under 4½ inches	5	20	3 6
4½ inches and under 4¾ inches	5	20	3 6
4¾ inches and under 5 inches	5	24	3 6
5 inches and under 5¼ inches	5	24	4 0
5¼ inches and under 5½ inches	5	28	4 0
5½ inches and under 5¾ inches	5	28	4 6
5¾ inches and under 6 inches	5	32	4 6
6 inches and over	5	35	5 0

[12] In cases where the length of the axle does not permit of these distances being adhered to, the distance between the points of support shall be as great as possible.

6. Tensile Test.—A standard test piece, C or D (see sketch, p. 47), machined cold from one end of each axle tested as above, must show a tensile breaking strength of 35 to 40 tons per square inch, with an elongation of not less than 25 per cent with 35 tons and 20 per cent with 40 tons, the sums of the intermediate tensile breaking

strengths and corresponding elongations being not less than 60. The yield point[13] must be not less than 50 per cent of the ultimate tensile strength.

7. Cold-Bend Test.—A test piece 9 inches long and 1¼ inches square, with one-sixteenth-inch radius at the edges, must withstand being bent cold through an angle of 90° around a bar 2½ inches diameter, and the test continued after the bar is removed by the ends being brought together without fracture.

(N. B.—This test will be taken only when a less number than 15 axles are ordered and the falling-weight test (clause 5) has not been carried out.)

8. Additional Tests Before Rejection.—In the event of the axle selected for testing not satisfying the requirements of the tensile or bend tests, and the fractured test piece indicating that the result does not fairly represent the bulk of the axles, the representative of the engineer (or of the purchaser) may, at his discretion, and at the expense of the manufacturer, take two more test pieces from the same axle for repeating the test under which failure occurred. The axles will be accepted if the results of the repeat tests are satisfactory.

Should the axle fail in the falling-weight test, the cast which the axle represents shall be rejected.

9. Independent Tests.—If the engineer (or the purchaser) desires to make independent tensile or other tests of the material, the broken pieces of any of the axles tested shall be placed at his disposal for the purpose, free of charge.

10. Reheating or Oil Treating.—All axles shall be either reheated or oil treated.

11. Inspection.—The representative of the engineer (or of the purchaser) shall have free access to the works of the manufacturer at all reasonable times; he shall be at liberty to inspect the manufacture at any stage, and to reject any material that does not conform to the terms of this specification.

12. Testing Facilities.—The manufacturer shall supply the material required for testing free of charge and shall, at his own cost, furnish and prepare the necessary test pieces, and supply labor and appliances for such testing as may be carried out on his premises in accordance with this specification. Failing facilities at his own works for making the prescribed tests, the manufacturer shall bear the cost of carrying out the tests elsewhere.

BRITISH STANDARD SPECIFICATION FOR CAR AXLES (WITHOUT ANALYSIS)

These specifications are identical with the preceding, except that in paragraph 1 no chemical analysis is specified.

BRITISH STANDARD SPECIFICATION FOR LOCOMOTIVE TIRES (WITH ANALYSIS)

1. Quality of Material.—The tires shall be manufactured from the highest quality of steel made from the best selected material by the acid open-hearth process, and must not show on analysis more than 0.035 per cent of sulphur or of phosphorus.

The manufacturer shall supply an analysis when required to do so.

2. Freedom from Defects.—The tires must be free from defects of any kind and accurately finished to the prescribed dimensions.

3. Branding.—The tires shall be distinctly stamped when hot, with such brands as the engineer (or the purchaser) may require, and in such a manner that these marks shall be legible when the tires are worn out.

4. Mechanical Tests.—Extra tires for testing in the manner described in clauses 5, 6, or 7 shall be provided by the manufacturer, at his own expense, at the rate of 2

[13] The yield point shall, for the purpose of this specification, be the load per square inch at which a distinctly visible increase occurs in the distance between gauge points on the test piece, observed by using dividers; or at which, when the load is increased at a moderately fast rate, there is a distinct drop of the testing machine lever, or, in hydraulic machines, of the gauge finger.

per cent of the tires ordered under the contract, or in such extra number as will allow of one tire being selected from each cast, and the representative of the engineer (or of the purchaser) shall select and test such of the tires as he may think proper to the extent of such percentage or extra number. The tires tested by deflection shall be handed over to the engineer (or to the purchaser) free of charge, if required, and shall be held to represent the average quality of the lot from which they were selected. After selection of tires for testing each test tire must comply with the following tests without further reheating or any other manipulation whatever either of the tires selected for testing or of any portion cut therefrom to furnish the test pieces.

5. **Falling-Weight Test.**—The tire shall be placed in a running position with the tread resting on a block of metal of not less than 5 tons weight supported on a rigid concrete or other solid foundation, and must withstand, without fracture, blows from a falling weight of 2240 pounds. The weight shall be allowed to fall freely onto the tread from heights of 10 feet, 15 feet, 20 feet, and upwards, until the deflection of the tire corresponds to that given by the following formula, in which d is the internal diameter of the tire, as rolled, in inches, and t is the thickness of the center of the tread, as rolled, in inches:

Class C: Tensile breaking strength 50 to 55 tons per square inch

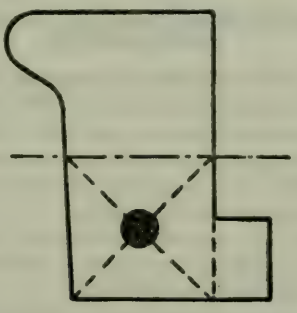
$$\frac{d^2}{50\,t^2}$$

Class D: Tensile breaking strength 56 to 62 tons per square inch

$$\frac{d^2}{55\,t^2}$$

In any case where the required deflection has been very nearly reached, the height of the final blow may be reduced at the discretion of the representative of the engineer (or of the purchaser).

6. **Tensile Test.**—A standard test piece, C (see sketch, p. 47), machined cold from each tire tested as above, and taken from the position shown in the sketch below must show the tensile breaking strength and minimum elongation given in the table, the intermediate elongations being in proportion.



Class	Tensile breaking strength in tons per square inch	Minimum elongation
		Per cent
C	50 to 55	13 to 11
D	56 to 62	10 to 8

7. Drop Test.—When so specified in the inquiry, each tire shall be allowed to drop freely in a running position, from the height specified below, upon a rail fastened to an iron block of not less than 2 tons in weight. Each tire shall then be turned round through an angle of 90° and dropped a second time.

Internal diameter of tire:	Up to 3½ feet	Over 3½ feet and up to 4½ feet	Over 4½ feet and up to 5½ feet	Over 5½ feet and up to 6½ feet	Over 6½ feet
Height of fall:	5 feet	4 feet	3 feet 6 inches	3 feet	2 feet 6 inches

8. Additional Tests Before Rejection.—In the event of the tire selected for testing not satisfying the requirements of clauses 5, 6, or 7, the representative of the engineer (or of the purchaser) shall, as specified below, make further tests, at the expense of the manufacturer, before finally refusing or accepting the tires represented.

(*a*) Should the tire fail in the falling-weight test, two more tires shall be taken from the same cast for testing, and the tires will be considered to have passed the test if these two tires fulfill the conditions of the falling-weight and tensile tests.

(*b*) Should the tire fail in the tensile test, and the fractured test piece indicate that the result does not fairly represent the bulk of the tires, two more tensile test pieces shall be taken from the same tire for repeating the test. The tires will be accepted if the results of the repeat tests are satisfactory.

9. Inspection.—The representative of the engineer (or of the purchaser) shall have free access to the works of the manufacturer at all reasonable times; he shall be at liberty to inspect the manufacture at any stage, and to reject any material that does not conform to the terms of this specification.

10. Testing Facilities.—The manufacturer shall supply the material required for testing free of charge and shall, at his own cost, furnish and prepare the necessary test pieces, and supply labor and appliances for such testing as may be carried out on his premises in accordance with this specification. Failing facilities at his own works for making the prescribed tests, the manufacturer shall bear the cost of carrying out the tests elsewhere.

BRITISH STANDARD SPECIFICATIONS FOR CAR (CARRIAGE AND WAGGON) TIRES (WITH ANALYSIS)

1. Quality of Material.—The tires shall be manufactured from the highest quality of steel made from the best selected material by the acid open-hearth process, and must not show on analysis more than 0.035 per cent of sulphur or of phosphorus.

The manufacturer shall supply an analysis when required to do so.

2. Freedom from Defects.—The tires must be free from defects of any kind and accurately finished to the prescribed dimensions.

3. Branding.—The tires shall be distinctly stamped when hot, with such brands as the engineer (or the purchaser) may require, and in such a manner that these marks shall be legible when the tires are worn out.

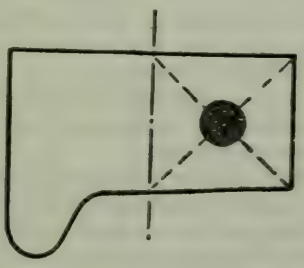
4. Mechanical Tests.—Extra tires for testing in the manner described in clauses 5, 6, or 7 shall be provided by the manufacturer, at his own expense, at the rate of 2 per cent of the tires ordered under the contract, or in such extra number as will allow of one tire being selected from each cast of 50, or two tires when a cast consists of more than 55, and the representative of the engineer (or of the purchaser) shall select and test such of the tires as he may think proper to the extent of such percentage or extra number. The tires tested by deflection shall be handed over to the engineer (or to the purchaser) free of charge, if required, and shall be held to represent the average quality of the lot from which they were selected. After selection of tires for testing each test tire must comply with the following tests, without further reheating or any other manipulation whatever, either of the tire selected for testing or of any portion cut therefrom to furnish the test pieces.

5. Falling-Weight Test.—The tire shall be placed in a running position, with the tread resting on a block of metal of not less than 5 tons weight supported on a rigid concrete or other solid foundation, and must withstand, without fracture, blows from a falling weight of 2240 pounds. The weight shall be allowed to fall freely onto the tread from heights of 10 feet, 15 feet, 20 feet, and upward, until the deflection of the tire corresponds to that given by the following formula, in which d is the internal diameter of the tire, as rolled, in inches, and t is the thickness at the center of the tread, as rolled, in inches:

Class B: Tensile breaking strength 42 to 48 tons per square inch	Class C: Tensile breaking strength 50 to 55 tons per square inch	Class D: Tensile breaking strength 56 to 62 tons per square inch
$\frac{d^2}{45\ t^2}$	$\frac{d^2}{50\ t^2}$	$\frac{d^2}{55\ t^2}$

In any case where the required deflection has been very nearly reached the height of the final blow may be reduced at the discretion of the representative of the engineer (or of the purchaser).

6. Tensile Test.—A standard test piece C (see sketch, p. 47), machined cold from each tire tested above, and taken from the portion shown in the sketch must show the tensile breaking strength and minimum elongation given in the table, the intermediate elongations being in proportion.



Class	Tensile breaking strength in tons per square inch	Minimum elongation
		Per cent
B	42 to 48	18 to 15
C	50 to 55	13 to 11
D	56 to 62	10 to 8

7. Drop Test.—When so specified in the inquiry, each tire shall be allowed to drop freely in a running position, from the height specified below, upon a rail fastened to an iron block of not less than 2 tons in weight. Each tire shall then be turned round through an angle of 90° and dropped a second time.

Internal diameter of tire	Up to 3½ feet.	Over 3½ feet.
Height of fall	5 feet.	4 feet.

8. Additional Tests Before Rejection.—In the event of the tire selected for testing not satisfying the requirements of clauses 5, 6, or 7 the representative of the engineer (or of the purchaser) shall, as specified below, make further tests, at the expense of the manufacturer, before finally refusing or accepting the tires represented.

(*a*) Should the tire fail in the falling-weight test, two more tires shall be taken from the same cast for testing, and the tires will be considered to have passed the test if these two tires fulfill the conditions of the falling-weight and tensile tests.

(*b*) Should the tire fail in the tensile test and the fractured test piece indicate that the result does not fairly represent the bulk of the tires, two more tensile test pieces shall be taken from the same tire for repeating the test. The tires will be accepted if the results of the repeat tests are satisfactory.

9. Inspection.—The representative of the engineer (or of the purchaser) shall have free access to the works of the manufacturer at all reasonable times; he shall be at liberty to inspect the manufacture at any stage and to reject any material that does not conform to the terms of this specification.

10. Testing Facilities.—The manufacturer shall supply the material required for testing free of charge and shall, at his own cost, furnish and prepare the necessary test pieces, and supply labor and appliances for such testing as may be carried out on his premises in accordance with this specification. Failing facilities at his own works for making the prescribed tests, the manufacturer shall bear the cost of carrying out the tests elsewhere.

BRITISH STANDARD SPECIFICATION FOR CAR (CARRIAGE AND WAGGON) TIRES (WITHOUT ANALYSIS)

1. Quality of Material.—The tires shall be manufactured from steel made from selected material by the acid open-hearth or acid Bessemer process.

2. Freedom from Defects.—The tires must be free from defects of any kind and accurately finished to the prescribed dimensions.

3. Branding.—The tires shall be distinctly stamped when hot with such brands as the engineer (or the purchaser) may require and in such a manner that these marks shall be legible when the tires are worn out.

4. Mechanical Tests.—Extra tires for testing in the manner described in clauses 5 and 6 shall be provided by the manufacturer, at his own expense, at the rate of 2 per cent of the tires ordered under the contract, or in such extra number as will allow of one tire being selected from each cast of 50, or two tires when a cast consists of more than 55, and the representative of the engineer (or of the purchaser) shall select and test such of the tires as he may think proper to the extent of such percentage or extra number. The tires tested by deflection shall be handed over to the engineer (or to the purchaser) free of charge, if required, and shall be held to represent the average quality of the lot from which they were selected. After selection of tires for testing, each test tire must comply with the following tests without further reheating or any other manipulation whatever either of the tire selected for testing or of any portion cut therefrom to furnish test pieces.

5. Falling-Weight Test.—The tire shall be placed in a running position, with the tread resting on a block of metal of not less than 5 tons weight supported on a rigid concrete or other solid foundation, and must withstand, without fracture, blows from a falling weight of 2240 pounds. The weight shall be allowed to fall freely onto the tread from heights of 10 feet, 15 feet, 20 feet, and upward until the deflection of the tire corresponds to that given by the following formula, in which d is the internal diameter of the tire, as rolled, in inches and t is the thickness at the center of the tread, as rolled, in inches:

Class B: Tensile breaking strength, 42 to 48 tons per square inch	Class C: Tensile breaking strength, 50 to 55 tons per square inch
$\frac{d^2}{45\ t^2}$	$\frac{d^2}{50\ t^2}$

In any case where the required deflection has been very nearly reached, the height of the final blow may be reduced at the discretion of the representative of the engineer (or of the purchaser).

6. Tensile Test.—A standard test piece C (see sketch, p. 47), machined cold from each tire tested as above, must show the tensile breaking strength and minimum elongation given in the table, the intermediate elongations being in proportion.

Class	Tensile breaking strength in tons per square inch	Minimum elongation
		Per cent
B	42 to 48	18 to 15
C	50 to 55	13 to 11

7. Additional Tests Before Rejection.—In the event of the tire selected for testing not satisfying the requirements of clauses 5 or 6, the representative of the engineer (or of the purchaser) shall, as specified below, make further tests at the expense of the manufacturer before finally refusing or accepting the tires represented.

(*a*) Should the tire fail in the falling-weight test, two more tires shall be taken from the same cast for testing, and the tires will be considered to have passed the test if these two tires fulfill the conditions of the falling-weight and tensile tests.

(*b*) Should the tire fail in the tensile test, and the fractured test piece indicate that the result does not fairly represent the bulk of the tires, two more tensile test pieces shall be taken from the same tire for repeating the test. The tires will be accepted if the results of the repeat tests are satisfactory.

8. Inspection.—The representative of the engineer (or of the purchaser) shall have free access to the works of the manufacturer at all reasonable times; he shall be at liberty to inspect the manufacture at any stage and to reject any material that does not conform to the terms of this specification.

9. Testing Facilities.—The manufacturer shall supply the material required for testing free of charge and shall, at his own cost, furnish and prepare the necessary test pieces and supply labor and appliances for such testing as may be carried out on his premises in accordance with this specification. Failing facilities at his own works for making the prescribed tests, the manufacturer shall bear the cost of carrying out the tests elsewhere.

BRITISH STANDARD SPECIFICATION FOR STEEL CASTINGS

1. Quality of Material.—The castings shall be manufactured from steel produced by an approved process, and must not show on analysis more than 0.07 per cent of sulphur or of phosphorus.

The manufacturer shall supply an analysis of each cast when required to do so.

2. Annealing.—All castings shall be thoroughly annealed in a suitable furnace before testing.

3. Molding.—The castings shall be accurately molded in accordance with the pattern or working drawing supplied by the engineer (or by the purchaser), with the addition of such lettering as may be prescribed.

4. Branding.—The cast number shall be stamped upon each casting, close to the molded number of the pattern.

5. Repairs to Defective Castings.—Any defects or unsound metal which a casting may have, from whatever cause arising, shall be left bare, and no filling with the object of obliterating such defects will be permitted unless previously sanctioned by the representative of the engineer (or of the purchaser). Any castings upon which such work has been done without such sanction having been obtained will be rejected.

6. Selection of Test Pieces.—The representative of the engineer (or of the purchaser) will examine all castings before delivery, and make a selection from the bulk of castings from which the specified tests are to be taken. He will select and stamp pieces for testing purposes, to be cut from the casting, or from lumps formed on each casting, of such size and in such a position in the mold as will furnish test pieces which shall be truly representative of the remainder of the metal.

7. Number of Tests.—The castings will be required to pass the tests specified below, according to classification. The class of castings shall be specified on the drawing.

CLASS A. GENERAL CASTINGS.—One tensile and one bend test shall be taken from each cast, and 2 per cent of the castings shall be selected by the representative of the engineer (or of the purchaser) from the bulk, to be tested to destruction.

In the case of less than 50 castings being ordered, one extra casting shall, when so specified in the inquiry, be provided by the manufacturer at his own expense for the destruction test.

CLASS B. WHEEL CENTERS.—One tensile test shall be taken from each cast and one bend test from each wheel center, but in the case of car[14] wheel centers one tensile test and one bend test shall be taken from each cast. When a destruction test is specified, the number of wheel centers selected to undergo this test shall not exceed 2 per cent.

In the case of less than 50 wheel centers being ordered, one extra wheel center shall, when so specified with the inquiry, be provided by the manufacturer at his own expense for the destruction test.

CLASS C. LARGE OR IMPORTANT CASTINGS.—One tensile test shall be taken from each cast, and one bend test from each casting.

8. Tensile Test.—A standard test piece D (see sketch, p. 47), having a gauge length of 3 inches and a sectional area of one-half square inch, or failing a 3-inch test piece, a standard test piece C (see sketch, p. 47) having a gauge length of 2 inches and a sectional area of one-fourth square inch, must, without reheating or any other manipulation whatever, show not less than the minimum tensile breaking strength and elongation given in the table.

Description of casting	Minimum tensile breaking strength per square inch	Minimum elongation
	Tons	Per cent
Castings with wearing surfaces	35	10
Other general castings and wheel centers	25	15

9. Cold-Bend Test.—In the case of castings other than those with wearing surfaces a test piece 9 inches long, turned to 1 inch diameter, must withstand being bent cold through an angle of 90° round a bar 2½ inches diameter without fracture.

10. Drop Test.—Each wheel center must withstand, without showing crack or flaw, being dropped onto a block of metal of not less than 5 tons weight supported on a rigid concrete or other solid foundation. The wheel center shall be raised and allowed to fall freely in a running position from a height of 3 feet on the end of a spoke (where such exists). In the case of wheel centers cast with balance weights the height may be reduced to 2 feet.

11. Ringing Test.—Each wheel center shall be suspended in a suitable position and struck with a quarter hammer on the rim and spokes (where such exist) and an examination made for any signs of blowholes or other defects.

[14] In all of the original British specifications the term "waggon" was used to indicate freight car.

12. Destruction Test.—When wheel centers are tested to destruction, the test shall be made by dropping the wheel center onto a block of metal of not less than 5 tons weight supported upon a rigid concrete or other solid foundation. The wheel center shall be raised and allowed to fall freely in a running position through distances of 5 feet and 10 feet on the end of a spoke (where such exists) and then turned through 90° and again raised and allowed to fall freely in a running position through distances of 5 feet and 10 feet on the end of a spoke (where such exists). Any sign of failure under this test will render the wheel centers represented liable to rejection. The test shall then be continued, the fall being increased 5 feet each time until fracture results or the wheel center is doubled up.

13. Additional Tests Before Rejection.—In the event of the casting selected for testing not satisfying the requirements of clauses 8, 9, and 12 the representative of the engineer (or of the purchaser) shall, as specified below, make further tests of castings, provided by the manufacturer at his own expense, before finally refusing or accepting the castings represented.

(*a*) TENSILE OR BEND TEST.—Should the casting fail in the tensile or bend test, and the fractured test piece indicate that the result does not fairly represent the bulk of the castings, then in castings coming under class A the tensile or bend test shall be repeated from pieces cut from the same lump.

The castings shall be accepted if this second test is satisfactory, and the whole upon close examination found free from defects.

Class B.—Tensile test pieces shall be taken from two more wheel centers from the same cast or two more bend tests shall be taken from pieces cut from the same lump.

The wheel centers shall be accepted if two of the three test results are satisfactory and the whole upon close examination found free from defects.

Class C.—Tensile test pieces shall be taken from two more castings from the same cast or two more bend tests shall be taken from pieces cut from the same lump.

The castings shall be accepted if two of the three test results are satisfactory and the whole upon close examination found free from defects.

(*b*) DESTRUCTION TEST.—Should the wheel center fail in the destruction test before enduring the first four blows and the fracture indicate that the result does not fairly represent the bulk, then two more wheel centers shall be taken for testing one from the same cast and the second from another cast. The wheel centers shall be accepted if two of the three test results are satisfactory.

14. Inspection.—The representative of the engineer (or of the purchaser) shall have free access to the works of the manufacturer at all reasonable times during the course of manufacture of the castings; he shall be at liberty to inspect the manufacture at any stage and to reject any casting or material that is unsound or does not otherwise conform to the terms of this specification.

15. Testing Facilities.—The manufacturer shall supply the castings, required under clause 7 for testing, free of charge, and shall, at his own cost, furnish and prepare the necessary test pieces and supply labor and appliances for making all tests on his premises in accordance with this specification. Failing facilities at his own works for making the prescribed tests, the manufacturer shall bear the cost of carrying out the tests elsewhere.

RAILWAY CLEARING HOUSE

STANDARD SPECIFICATION FOR THE CONSTRUCTION OF PRIVATE OWNERS' 8, 10, AND 12 TON FREIGHT CARS AND FOR THE RECONSTRUCTION OF 8 AND 10 TON FREIGHT CARS; ALSO FOR THE CONVERSION OF 8 AND 10 TON DEAD-BUFFERED FREIGHT CARS TO WORK UPON THE LINES OF THE RAILWAY COMPANIES (DECEMBER, 1907)†

13. Tires.—The tires to be made of acid open-hearth or acid Bessemer steel.

The tires to be 5 inches wide and not less than 2 inches nor more than 2½ inches thick on tread when finished, truly bored out, with not more than one-sixteenth

of an inch allowance for contraction. Tires to be secured to the wheels by the method of fastening shown on the standard drawings.

14. **Axles.**—The axles to be made of acid open-hearth or acid Bessemer steel.

15. **Axles, 8 and 10 Ton Cars.**—For 8 and 10 ton cars the axles to be 6 feet 6 inches in length from center to center of journals, 5¼ inches diameter through the boss of the wheel, and gradually tapered to 4½ inches in the middle. There must be no shoulder on the axle behind the boss. The journals to be 8 inches long by 3¾ inches diameter.

Axles are to be discarded when the journals are, in the case of 8-ton cars, worn below 3⅜ inches, and in the case of 10-ton cars below 3½ inches in diameter.

16. **Axles, 12-Ton Cars.**—For 12-ton cars the axles to be 6 feet 6 inches in length from center to center of journals, 5½ inches diameter through the boss of the wheel, and gradually tapered to 4⅞ inches in the middle. There must be no shoulder on the axle behind the boss. The journals to be 9 inches long by 4¼ inches diameter.

Axles under 12-ton cars are to be discarded when the journals are worn below 3⅞ inches in diameter.

17. **Wheels (Drawings 6, 151, 152, 153, 154, and 155).**—The body of the wheel to be made of wrought iron with eight solid or open spokes, or of mild steel or cast steel with eight solid spokes, to the dimensions shown on the standard drawings.

All wheel skeletons to be turned exactly to 2 feet 9 inches diameter.

The bosses must be bored out, and the wheels then forced untired onto the axle by hydraulic pressure of not less than 50 tons for 8 and 10 ton cars and 60 tons for 12-ton cars.

No keys are to be used.

21. **Repairs and Reconstruction.**—WHEELS.—For 8-ton cars, wheel spokes to be not less than $2\frac{15}{16}$ inches wide by $\frac{11}{16}$ inch thick; rims not less than 2⅞ inches wide by ⅝ inch thick.

For 10-ton cars, wheel spokes must not be less than $3\frac{7}{16}$ inches wide by $\frac{11}{16}$ inch thick; rims not less than 3¼ inches wide by ⅝ inch thick.

TIRES.—The tires to be not less than 5 inches wide, and when turned up to be not less than 1¼ inches thick.

Tires fastened onto the wheels with rivets or bolts to be allowed to run until the wheels require re-tiring, when they must be re-tired in the way shown on the drawings of the standard specification.

STANDARD SPECIFICATIONS AND DRAWINGS FOR PRIVATE OWNERS' FREIGHT CARS (DECEMBER, 1907) †

[Addendum to standard specifications and drawings for private owners' freight cars]

5. **Wrought-Iron Axles.**—Wrought-iron axles will be accepted where required provided they pass the following tests, and on the understanding that when a specification for iron axles is issued by the British standards committee the tests provided therein will be substituted:

TENSILE TEST.—A test piece of half a square inch area cut from any part of the axle tested or from the ends left on the forgings to give an ultimate strength of not more than 23 tons and not less than 20 tons per square inch, with not less than 25 per cent elongation measured over a parallel length of 3 inches.

(NOTE.—The axles must also comply with the falling-weight test as stipulated in the 1904 specification.)

6. **Wheels.**—Tired wheels may be forced on the axles, the pressures, however, being increased 10 tons in each case above that specified.

STANDARD SPECIFICATIONS AND TESTS FOR MATERIALS TO BE USED IN THE CONSTRUCTION OF PRIVATE OWNERS' FREIGHT CARS TO WORK UPON THE LINES OF THE RAILWAY COMPANIES (DECEMBER, 1907)†

TIRES AND AXLES

3. (*a*) The tires and axles shall be manufactured from acid open-hearth or acid Bessemer steel made from selected material.

(*b*) The tires and axles must be free from defects of any kind and accurately finished to the prescribed dimensions.

(*c*) The tires and axles to be stamped, while hot, with the day, month, and year when made, and the maker's name, and also blow or cast number to be well stamped upon each axle and on the outer face of each tire.

(*d*) The tires or axles passed by the inspector will be stamped by him, the impression of the stamp being in all cases placed close to and, where practicable, above the maker's name, so that the impression may be clearly visible to the inspector who inspects the car under which the particular tire or axle is placed.

(*e*) All stamping to be done in such a manner that the marks shall be legible when the tires and axles are worn out.

4. **Testing of Tires.**—(*a*) Extra tires for testing in the manner described in subclauses (*b*), (*c*), and (*d*) shall be provided by the manufacturer, at his own expense, at the rate of 2 per cent of the tires ordered under the contract, or in such extra number as will allow of one tire being selected from each cast, and the inspector shall select and test such of the tires as he may think proper to the extent of such percentage or extra number. The tires tested by deflection shall be held to represent the average quality of the lot from which they were selected. No tire to be less in diameter than 3 feet 1 inch on tread, and the tire selected for testing must comply with the following test without reheating or any other manipulation whatever, either of the tires selected for testing or any portion cut therefrom to furnish the test pieces.

(*b*) The tire shall be placed in a running position, with the tread resting on a block of metal of not less than 5 tons weight supported on a rigid concrete or other solid foundation, and must withstand without fracture blows from a falling weight of 2240 pounds. The weight shall be allowed to fall freely onto the tread from heights of 10 feet, 15 feet, 20 feet, and upward, the tire to deflect 1 inch for every 8 inches of its internal diameter.

In any cast where the required deflection has been very nearly reached the height of the final blow may be reduced at the discretion of the inspector.

(*c*) A standard test piece, C (p. 47), machined cold from each tire, tested as above, and taken from the position (shown in sketch, p. 47), must show the tensile breaking strength and minimum elongation given in the table, the intermediate elongations being in proportion.

Class	Tensile breaking strength in tons per square inch	Minimum elongation, per cent over parallel length of 2 inches
A	35 to 40	25 to 20
B	42 to 48	18 to 15

(*d*) In the event of the tire selected for testing not satisfying the requirements of subclauses (*b*) or (*c*) the inspector shall, as specified below, make further tests, at the expense of the manufacturer, before finally refusing or accepting the tires represented.

(*i*) Should the tire fail in the falling-weight test, two more tires shall be taken from the same cast for testing, and the tires will be considered to have passed the test if these two tires fulfill the conditions of the falling-weight and tensile-tests.

(*ii*) Should the tire fail in the tensile test and the fractured test piece indicate that the result does not fairly represent the bulk of the tires, two more tensile test pieces shall be taken from the same tire for repeating the test. The tires will be accepted if two of the three test results are satisfactory.

5. Testing of Axles.—(*a*) Extra axles for testing in the manner described in subclauses (*b*), (*c*), and (*d*) shall be provided by the manufacturer, at his own expense, at the rate of 2 per cent of the axles ordered under the contract, but, with the exception stated below, one extra axle shall be provided from each cast, and the inspector shall select and test such of the axles as he may think proper to the extent of such percentage or extra number. The axles tested shall be held to correctly represent the quality of the casts from which they were made. In the case of a less number than 15 axles being asked for under the contract, or less than 15 being made from each cast, the manufacturer may either (1) provide an extra axle for testing or (2) leave a piece on each axle of the same diameter as the forged end of the axle, to enable the inspector to stamp one such piece from which test pieces may be cut for the tensile test and cold-bend test specified in subclauses (*c*) and (*d*). Each axle selected for testing must comply with the following tests without reheating or any manipulation whatever either of the axle selected for testing or any portion cut therefrom to furnish the test pieces.

(*b*) The axle shall be placed upon bearings resting upon a block of metal of not less than 5 tons weight supported on a rigid concrete or other solid foundation and must withstand, without fracture, five blows from a falling weight of 2240 pounds, as specified below. The axle shall be turned after every blow and shall be broken in the center after testing.

	Distance apart of bearings	Height of fall
	Ft. in.	Feet
8, 10, or 12 ton cars, 10-ton tank cars, and 10-ton tank cars for conveying class A inflammable liquids	3 6	20
15 and 30 ton cars and 12-ton tank cars	3 6	22
20-ton cars and 20-ton tank cars	4 0	30

(*c*) A standard test piece, D (see sketch, p. 47), machined cold from one end of each axle tested as above must show a tensile breaking strength of 35 to 40 tons per square inch, with an elongation of not less than 25 per cent with 35 tons and 20 per cent with 40 tons, the sums of the intermediate tensile breaking strengths and corresponding elongations being not less than 60. The elastic limit must not be less than 50 per cent of the ultimate tensile strength.

(*d*) A test piece 9 inches long and 1¼ inches square, with $\frac{1}{16}$-inch radius at the corners, must withstand being bent cold through an angle of 90° round a bar 2½ inches diameter, and the test continued after the bar is removed by the ends being brought together without fracture.

(N. B.—This test will be taken only when a less number than 15 axles is ordered and the falling-weight test (subclause (*b*)) has not been carried out.)

(*e*) In the event of the axle selected for testing not satisfying the requirements of subclauses (*b*), (*c*), or (*d*), the inspector shall, as specified below, make further tests, at the expense of the manufacturer, before finally refusing or accepting the axles represented.

(*i*) Should the axle fail in the falling-weight test, two more axles shall be taken from the same cast for testing, and the axles will be considered to have passed the test if these two axles fulfill the conditions of the falling-weight and tensile tests.

(*ii*) Should the axle fail in the tensile or bend test, and the fractured test piece indicate that the result does not fairly represent the bulk of the axles, two more test pieces shall be taken from the same axle for repeating the test under which failure occurred. The axles will be accepted if two of the three test results are satisfactory.

(*f*) If the engineer (or the purchaser) desires to make independent tensile or other tests of the material, the broken pieces of any of the axles tested shall be placed at his disposal for the purpose free of charge.

(*g*) All axles shall be either annealed or oil hardened.

STEEL CASTINGS (WHEEL CENTERS)

6. (*a*) The castings shall be manufactured from steel produced by the open-hearth or other approved process and must not show on analysis more than 0.07 per cent of sulphur or of phosphorus. The manufacturer shall supply an analysis of each cast when required to do so.

(*b*) All castings shall be thoroughly annealed in a suitable furnace before testing.

(*c*) The castings shall be accurately molded in accordance with the pattern or working drawing, with the addition of such lettering as may be prescribed.

(*d*) The cast number shall be stamped upon each casting, close to the molded number of pattern.

(*e*) Any defects or unsound metal which a casting may have, from whatever cause arising, shall be left bare, and no filling with the object of obliterating such defects will be permitted unless previously sanctioned by the inspector. Any castings upon which such work has been done without such sanction having been obtained will be rejected.

(*f*) The inspector will examine all castings before delivery and make a selection from the bulk of castings from which the specified tests are to be taken. He will select and stamp pieces for testing purposes, to be cut from the casting, or from lumps formed on each casting of such size and in such a position in the mold as will furnish test pieces which shall be truly representative of the remainder of the metal.

(*g*) The castings will be required to pass the tests specified below according to classification. The class of castings shall be specified on the drawing.

CLASS A. SMALL GENERAL CASTINGS.—One tensile and one bend test shall be taken from each melting, and 2 per cent of the castings shall be selected by the inspector from the bulk, to be tested to destruction.

CLASS B. WHEEL CENTERS.—One tensile test and one bend test shall be taken from each melting. When a destruction test is specified, the number of wheel centers selected to undergo this test shall not exceed 2 per cent.

In the case of less than 50 wheel centers being ordered, one extra wheel shall, when so specified with the inquiry, be provided by the manufacturer at his own expense for the destruction test.

(*h*) A standard test piece D (see p. 47), having a gauge length of 3 inches and a sectional area of one-half square inch, or failing a 3-inch test piece, a standard test piece, C (see p. 47), having a gauge length of 2 inches and a sectional area of one-fourth

square inch, must, without reheating or other manipulation whatever, show the minimum tensile breaking strength and elongation given in the table.

Description of casting	Minimum tensile breaking strength per square inch	Minimum elongation
	Tons	Per cent
Castings with wearing surfaces	35	10
Other general castings and wheel centers	26	15

(*i*) In the case of castings other than those with wearing surfaces, a test piece 9 inches long, turned to 1-inch diameter, must withstand being bent through an angle of 90° round a bar 2½ inches diameter without fracture.

(*j*) Each wheel center must withstand, without showing crack or flaw, being dropped onto a block of metal of not less than 5 tons weight, supported on a rigid concrete or other solid foundation. The wheel center shall be raised in a running position and allowed to fall freely from a height of 3 feet on the end of a spoke.

(*k*) Each wheel center shall be suspended in a suitable position and struck with a quarter hammer on the rim and spokes, and an examination made for any signs of blowholes or other defects.

(*l*) When wheel centers are tested to destruction, the test shall be made by dropping the wheel center onto a block of metal of not less than 5 tons weight supported upon a rigid concrete or other solid foundation. The wheel center shall be raised in a running position and allowed to drop freely 5 feet and 10 feet over the end of a spoke, and then turned through 90° and again raised in a running position and allowed to fall freely 5 feet and 10 feet on the end of a spoke. Any sign of failure under this test will render the wheel centers represented liable to rejection. The test shall then be continued, the fall being increased 5 feet each time until fracture results or the wheel center is doubled up.

(*m*) In the event of the casting selected for testing not satisfying the requirements of subclauses (*h*), (*i*), and (*l*), the inspector shall, as specified below, make further tests of castings, provided by the manufacturer at his own expense, before finally refusing or accepting the castings represented.

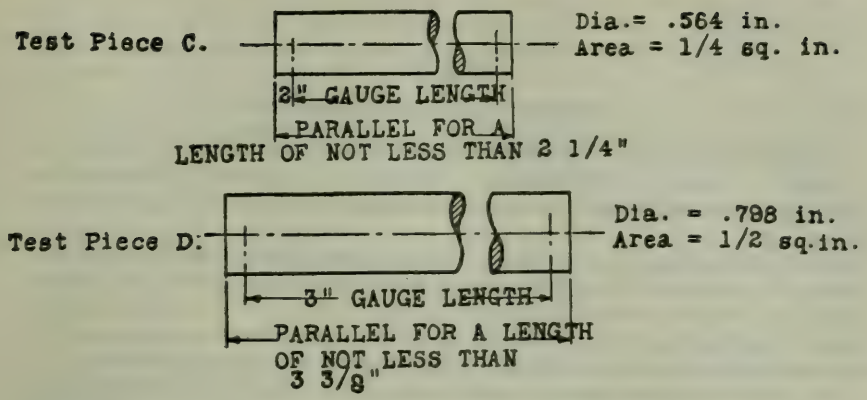
(*i*) Tensile or Bend Test.—Should the casting fail in the tensile or bend test, and the fractured test piece indicate that the result does not fairly represent the bulk of the castings, then in castings under class A the tensile or bend test shall be repeated from pieces cut from the same lump.

The castings shall be accepted if this second test is satisfactory and the whole, upon close examination, found to be free from defects.

Class B.—Tensile and bend test pieces shall be taken from two more wheel centers from the same melt.

The wheel centers shall be accepted if two of the three test results are satisfactory and the whole, upon close examination, found free from defects.

(*ii*) Destruction Test.—Should the wheel center fail in the destruction test before enduring the first four blows, and the fracture indicate that the result does not fairly represent the bulk, then two more wheel centers shall be taken for testing, one from the same cast and the second from another cast. The wheel centers shall be accepted if two of the three test results are satisfactory.



Forms of British Standard Tensile Test Pieces.

(The sketches for forms C and D, referred to in the preceding text of British standard specifications, are here given.)

ITALY

ITALIAN STATE RAILWAYS

SPECIFICATION FOR SUPPLYING OF STEEL RAILS FOR TRACKS (1913 EDITION)

Article 1. Object of the Specifications.—The scope of the present specification is to establish the technical conditions to which the furnishing of steel rails for tracks shall be subject.

Art. 2. Profile—Section of the Rail.—The transverse section of the rails must conform to the drawings that will be transmitted to the contractor when the order is placed and must be constant throughout the length of the rail.

Only the following tolerance will be admitted: One millimeter, more or less, in the base of the rail; one-half millimeter, more or less, in all other dimensions.

The distance from the planes of the tie-plates (piani di steccatura) measured along any line parallel to the vertical axis of the rail shall not exceed by more than one-fourth millimeter the distances given in the sketches. No tolerance is allowed in the inclination of these planes with respect to the axis of the rail.

Art. 3. Length of the Rails.—(The paragraphs dealing with the actual lengths of the rails to be used are here omitted; they vary from 11.8 to 12.1 meters.)

The rails shall be measured with an iron rule previously checked by the inspector and must have the prescribed lengths at 15° C. A tolerance of 2 mm. is allowed in the length of all rails.

Art. 4. Normal Weight.—The normal weights per meter of rails are fixed as follows:

Type	Kilograms
FS 50[6]	50.600
FS 46[3]	46.300
RA 36 S and RA 36 D	36.100
SR 27[3]	27.300

Art. 5. Production of Steel.—The rails shall be made exclusively of soft steel obtained by the converter process, acid or basic, or by the Martin process, acid or basic. Every firm submitting bids for the supply of the rails must declare in the offer the process that it intends to use in the manufacture of steel.

Art. 6. Dimensions and Treatment of the Ingots.—The central cross section of the ingot shall be equal to 20 times the cross section of the rolled rails for the rails RA 36 S, RA 36 D, and SR 27[3], and 25 times for the rails, model FS 50[6], FS 46[3].

The ingots after pouring shall be maintained in a vertical position until they are completely solidified to the center.

The manufacturing company must produce the ingots for rails to be delivered.

When, after pouring, the ingots are not taken directly to the rolls they shall be punched with their heat number as soon as their temperature permits and placed where they can be distinguished from those of other heats without possibility of mistake.

Art. 7. The Rolling.—The rolling shall be conducted in such a manner that the rails will come out straight from the rolls without flaw or discontinuity of any sort.

The finishing temperature of the rails shall be such as to assure a fine grain and homogeneous structure.

The rails shall bear the rolling mark very clearly in relief indicating the name of the manufacturing company, year of the rolling in ordinary figures, the month in Roman figures, and the type of rail.

They shall also bear letters signifying the manufacturing process used; that is, the letters B, T, MA, MB, according to whether they have been made of Bessemer, Thomas, Martin acid, or Martin basic steel. (There are omitted special clauses dealing with the size and position of the marks to be rolled into the rails.)

Art. 8. Sawing of the Rails.—The rails must be cut with the hot saw after coming from the rolls. In case only one rail is obtained from an ingot the discard shall not be less than 1½ meters of the upper part of the ingot and seven-tenths meter from the lower.

In the case where the ingot furnishes more than one rail, the discard coming from the upper part of the ingot shall be 1½ meters plus as many times 50 cm as there are other rails coming from the same ingot. In any case the discard from the end of the ingot must have such a length that the end of the rails shall have a sound and uniform structure.

When rolling more rails than one from an ingot, the company is not allowed to take a discard from the lower part of the ingot greater than that prescribed above or which is necessary in order to have a sound structure in the last rail.

Art. 9. Marking of the Rails as They Come from the Rolls.—The rails as they come from the rolls are marked with the hot punch with the number of the heat to which they belong, at a distance of about 1 meter from one end. When more than one rail is obtained from one ingot, the rail nearer the upper part of the ingot must be marked A, and the other rails, successively, with the letters B, C, etc., near the heat number.

When the rails have been milled and arranged on beds or platforms to be inspected, they are to be stamped at the end of each rail with the number of the heat, and those from the upper part of the ingot with A, etc.

Art. 10. Straightening and Cooling of the Rails.—The rails after rolling shall be left to cool slowly on level rail beds and shall not be placed the one on the other until they have been cooled sufficiently. Under no circumstances are they to be left exposed to rain or snow while they are hot.

The transportation of the hot rails and all disposition during the cooling shall be such that the rails are after cooling almost straight. The small deviations from perfect straightness, which remain after cooling, shall be removed by cold straightening in a press, with the application of blows of small force. Rails badly out of alignment shall be rejected.

Art. 11. Milling and Beveling of the Heads of the Rails.—The straightened rails shall be milled perfectly square at both ends to the prescribed length.

The heads shall be beveled at both ends in conformance with the design.

The longitudinal fin shall be removed with the file.

Art. 12. Drilling of the holes.—The number and dimensions of the holes for each rail shall conform to the design. The holes shall be drilled in the horizontal boring machine; other means of producing the holes are rigorously prohibited. The axes of the holes must be perpendicular to the plane of the web. A tolerance of 1 mm in the position and diameter of the holes with respect to the specified dimensions is allowed.

Art. 13. Tarring.—The number of rails indicated in the specifications must be covered with a mixture of one part of pitch and two parts of tar. (This paragraph is not complete; directions are given for the application of the tar preparation.)

Art. 14. Special Marks for Special Types of Rails.—(This paragraph is here omitted.)

Art. 15. Repairing—Exterior Appearance.—It is not permitted to reheat the rails in order to reduce the length or to make any repairs.

Any rails which present traces of welding or any attempt to cover up defects of rolling will be rejected without further examination.

Small surface chips (paglie) shall be removed with the chisel in the presence of the agent of the railway administration.

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Rails presenting traces of fissure on the heads, chips (paglie) of any size cracks, seams, veins of scoriæ, or other defects that would alter the strength or would give rise to roughness or cavities, especially on the surface of the head and the web, shall be rejected.

Art. 16. The Testing.—Specification of the tests to be carried out:

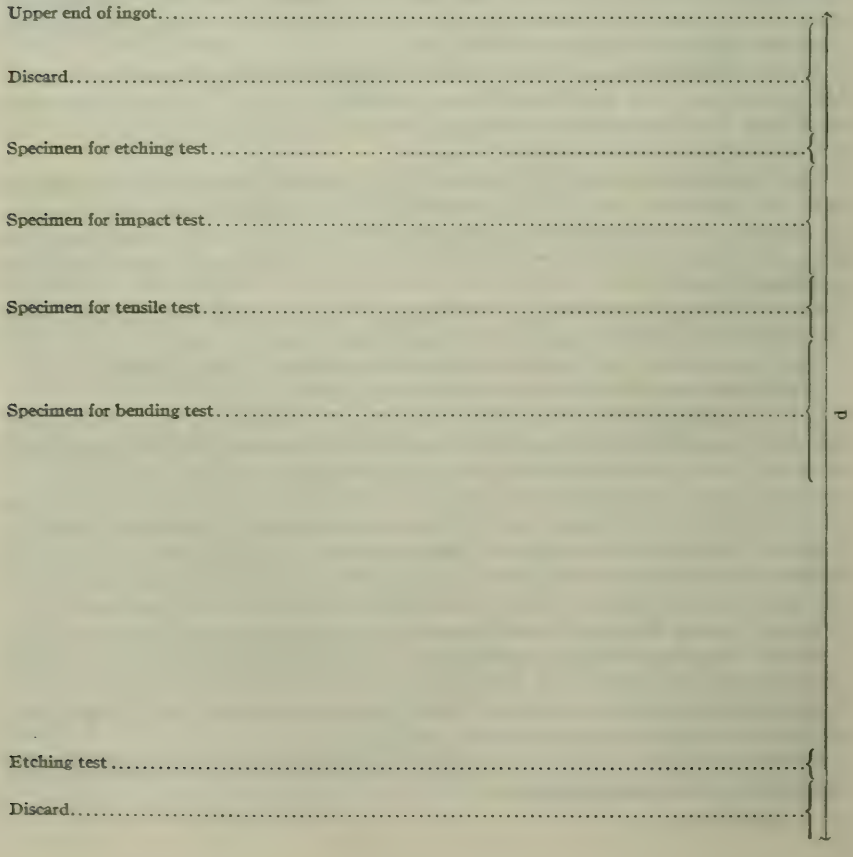
There shall be two groups of tests, one on rails taken by heat and others on rails of groups comprising many heats and which have passed the first test favorably. Each latter group shall be composed of not more than 200 rails; the arranging of the heats in groups shall be done by the agent of the railway.

The test by heats consists in one impact test. The tests by groups consist in one bending test, one tensile test, and two etching tests.

METHOD OF TAKING TEST SPECIMENS.—The specimen for the impact test shall be of a length of about 1½ m and shall be taken hot from a rail of each heat coming from the upper part of the ingot.

The specimens for the test by group shall be taken hot from one of the rails from which have been taken the specimens for the test by heats, and all of these specimens shall be marked hot with the number of the heat. On the specimen for the impact test shall be stamped the letter U and on those for the etching test the letter A or the letter B, according to whether they refer to the end corresponding to the upper or to the lower part of the ingot.

The following diagram indicates in which way the various test specimens shall be taken from the rail:



The distance *d* shall be an exact multiple of the normal length of the rail.

In order to hasten the inspection and testing of the rails the tests by heats shall be carried on at the same time as the tests by groups, provided that in case the test by heats shall not be passed favorably in any one case that heat shall not be included in a group, and another heat will be substituted.

In the case that the company wishes to avoid using a normal length of rail for each test by heats it is permitted the inspector to accept—

1. A specimen for the impact test taken hot from a rail of each heat from the discard corresponding to the upper part of the ingot.

2. Specimens for the etching tests taken hot from the two discards of one rail above referred to, one in each part and in the immediate vicinity of the ends of the rail (in a case where one rail is obtained from one ingot), or of the first and of the last rail, in the case of the rolling of several from the same ingot.

3. One specimen for the bending test taken hot from the discard corresponding to the upper part of the ingot from another rail bar of the same heat, from which shall be taken the specimens for the etching tests.

4. One specimen for the tensile test taken cold from the specimen taken for the impact or bending test and appertaining to that heat from which were taken the specimens for the corrosion and bending tests.

It is understood that when the company (manufacturer) takes advantage of this concession the results of the tests shall not be called in question and shall have the same value as those obtained in the way first indicated.

Impact Test.—The specimen placed with the base upon two supports at a distance of 1.1 m, the supports having the form of a knife-edge with rounded edges, with a radius not greater than 125 mm, shall resist without breaking or cracking a blow of 5100 kg m for the rails model FS 50^6; 4800 kg m for the rails model FS 46^3; 4000 kg m for the rails model RA 36 S and RA 36 D; 2700 kg m for the rails model SR 27^3.

The specimen turned through 180° on the supports shall then support a second blow of an equal force upon the base without breaking.

The hammer shall be of a weight of 600 kg and shall have the striking head rounded with a radius of not more than 125 mm.

In the foundation of the supports shall be excluded materials which are elastic or yielding. The said supports shall be fixed to an anvil of pig iron and that embedded in a mass of masonry.

If the test does not give the results expected, it shall be repeated upon two other specimens of the same heat selected from two rails taken from the rail beds, and when possible from two discarded rails, and taken from that part of the rail corresponding to the higher part of the ingot.

When from one ingot more rails than one are taken, the rails to be selected for the test shall be those marked with the letter A.

If also one of these other two specimens do not pass the test, the entire heat shall be rejected. If both of such specimens satisfy the impact test, the heat shall be admitted into the group tests.

Method of Carrying Out the Group Tests—*Bending Test.*—The specimen of the length of 1½ m placed upon two supports 1 m apart must support at the center of the span for a time of five minutes a weight of 35 000 kg for the rails model FS 50^6; 32 000 kg for the rails model FS 46^3; 22 000 kg for the rails model RA 36 S and RA 36 D; 15 000 kg for the rails model SR 27^3, without giving any permanent deformation after the load has been removed. The same piece shall then be subjected to a load of 58 000 kg for the models FS 50^6, and FS 46^3; 40 000 kg for the models RA 36 S and RA 36 D; 27 000 kg for the model SR 27^3: and must not break or show any signs of fissuring.

Tensile Test.—From the center of the head of the specimen to be tested in tension shall be taken cold a bar of circular cross section having a test length of 200 mm and

a diameter of 20 mm. The axis of the small bar taken must be 20 mm below the surface of the head of the rail measured along the vertical axis of the profile of the rail.

The test specimen must have a tensile strength of not less than 65 kg per square millimeter.

The elongation in per cent of the test length of 200 mm shall be such that the product of it by the breaking load expressed in kilograms per square millimeter shall not be inferior to 900 for the rails having a tensile strength equal to or less than 72 nor inferior to 800 for those having a resistance equal to or less than 75 and greater than 72 nor inferior to 750 for those having a higher tensile strength.

All of these tests shall be carried out at a temperature between 12° and 30° C.

Etching Tests.—The specimens shall have a length of 10 to 15 cm and the transverse surface shall be ground, polished, and cleaned with chloroform or ether.

The specimens shall be attacked by a chemical reagent to be selected by the inspector or agent of the railway.

The results of the test must show that the steel has a homogeneous structure and is not segregated. Only a small amount of segregation will be allowed corresponding to the center of the specimens taken from the part of the rails coming from the upper part of the ingot.

Any decision as to results of the etching tests rests exclusively with the agent of the company. If one of the results of the tensile, bending, or etching tests shall not satisfy the prescribed requirements, the test giving deficient results shall be repeated upon two other rails of the same heat taken from the rail beds (if possible from discarded rails), the specimens to be taken from the part of the rail corresponding to the upper part of the ingot. If only one of the results of the new tests shall be unfavorable, the entire heat corresponding shall be rejected and another test on another rail of the same group shall be carried out, and if it is possible belonging to a heat near to the one discarded. If such tests give results even partially unfavorable, the whole group shall be rejected.

When from an ingot several rails are obtained, the rails to be selected for the retest shall be those having the mark "A". In this case when one of the results of the new tests shall be unfavorable before proceeding to a definite rejection of the heat it will be permitted to carry out two tests on the rails B, and if both of these shall pass the test satisfactorily, all of the rails of this heat except the A rails may be accepted.

Miscellaneous.—Besides the tests indicated above the inspector has the right to carry out any other tests (cold or hot shortness, tempering, hardness, cold-bending test on a welded specimen, etc.) that he considers of importance for the selecting of the heat upon which to carry out the group tests and in general to assure himself of the good quality of the metal with respect to the use to which it is designated, and not excluding direct tests on the ingot, which, however, shall not be in greater number than one per thousand ingots.

Art. 17. Chemical Composition.—On all of these heats which shall be indicated by the inspector there shall be carried out by the contractor a quantitative chemical analysis and such results shall be delivered to the agent of the railway, who has also the right to assist or to be present at the carrying out of the chemical analysis.

The composition of the material shall be such as not to contain more than 0.10 per cent of phosphorus or more than 0.07 per cent of sulphur.

Art. 18. Surveillance of the Manufacture and Inspection.—At the beginning of each rolling there will be taken cold two small pieces for each model, which will serve the inspector to verify whether the profile is exact, and only after such examination, and after obtaining permission of the inspector will the contractor be allowed to continue with the rolling. The two pieces accepted will be stamped by the inspector and sent by the contractor to the general office of the railway administration in Rome. The inspector must satisfy himself from time to time by taking other pieces in the manner above indicated, during the period of rolling, that the profile is being cor-

rectly reproduced. If on account of unfavorable results of the group or heat tests, especially if accompanied by unfavorable results of any of the miscellaneous tests and of the chemical analysis, or if through defects, failures, or irregularities that would come out during the various operations of testing, the inspector has reason to doubt the good quality of the rails the Administration of State Railways shall have the right to reject the whole order.

Art. 19. Weight of the Rails.—The average weight of the rails per meter is obtained by weighing 5 per cent of the rails received. The rails to be weighed shall be selected by the inspector in the various periods of rolling. If the weights as determined differ by more than 1 per cent from the normal weight referred to in paragraph 4, the State Railway Administration has the right to reject the whole lot.

FRANCE

EASTERN RAILWAYS

SPECIFICATIONS FOR STEEL RAILS OF THE TYPE VIGNOLE, 46K (1910)

1. The present specifications concern the furnishing of steel rails of the type Vignole, 46k.

2. **Profile and Weight of Rails.**—The rails must be of the form shown in the drawings and of the templets, which shall be furnished the contractor. The profile shall be rigorously adhered to over the whole length of the rail bars, and particularly at the ends, where care shall be taken not to compress or alter the section at the time of cutting.

The rails which do not reproduce exactly the form of the templet shall be rejected.

There is accorded a tolerance of +1 per cent on the weight of the rails, which are rigorously exact, nevertheless, but this is only for the purpose of allowing for the wear and play of the rolls. This tolerance shall not be applicable to rails of which the profile is not perfectly symmetrical.

The weight of 1 meter of the rail shall be determined on 100 rail bars of a section perfectly in accordance with the templet of the company.

The excess weight in total amount of each lot delivered over the normal weight increased by 1 per cent shall not be paid for.

The current manufacture of the rails shall not be authorized by the chief engineer of track until after examination of the samples submitted by the mill.

3. **Length of the Rails.**—The delivery shall comprise 80 per cent of rails, 18 m long (including those of 17.96 m and 17.90 m for laying in curves), and 20 per cent of rails 12 m long (including those of 11.96 m and 11.90 m for laying in curves), of sublengths and of coupons destined for the construction and laying of track auxiliaries.

In addition to 80 per cent of long rails, the Eastern Railway may ask for 4 per cent of rails of 24 m (including those of 23.96 m and 23.90 m for laying in curves).

The proportion of rails for use in curves will be determined as needed by the chief engineer of the railroad.

In order to facilitate the manufacture of the rails, the manufacturer may take from the 18 m rails, rejected for local defects at the ends, a portion of the 12 m rails, which he is to supply. These 12 m rails may contain the holes drilled for the splice bars.

The rails of 24 m, 23.96 m, and 23.90 m shall be tarred.

A tolerance of ±2 mm (0.002 m) will be allowed in the length of each rail.

36^{k} rails for track auxiliaries will be ordered three months in advance by letters, the order including, at least 300 tons in lengths ranging from 2 to 12 m.

4. **Marking of the Rails.**—The rails shall bear at least on one side of the web letters and figures in relief indicating the year and month of manufacture and the name of the firm furnishing them. The number of the heat shall also be marked on the rail and the letter H at the end of each rail bar nearest to the top of the ingot.

5. **Quality of the Material and Manufacture of the Rails.**—The ingots for the manufacture of rails shall have a rectangular cross section with rounded angles, or an equivalent circular section, and the weight shall be sufficient to obtain, after rolling, discards of at least a length of 2.50 m for the rail bars. The discard corresponding to the top of the ingot shall be at least 1.50 m long. The surface of the ingots must be sound and uniform. The burrs and mold seams shall be chipped off with chisel. Every ingot which shows faults or breaks in continuity shall be rejected.

The agent of the company shall have the right to be present at the tests. He may make with specimens taken at the moment of casting of the ingots bending or quenching tests.

The rolling shall be as perfect as possible; the surfaces of the rails shall be sound and uniform, and the rails when finished may show neither splinters (pailles) nor fissures (criques).

The fracture must show a fine structure, fibrous (texture á arrachments), uniform and free from white or crystalline areas.

Rails which show traces of repair will be rejected.

6. Finishing and Straightening.—The rails must be as nearly straight after cooling as possible, but may be cold straightened finally in the press somewhat, care being taken to use a nonimpact and gradual pressure in the process so as to avoid fissures.

All of the rails must be cut at both ends perpendicularly to the axis; the ends must be sound and uniform without burrs (bavures) and suitably finished. The rails may not be reheated for this operation.

7. Boring of the Tie-Plate Holes.—The order will indicate whether, for the tie-plates, the rails are to be bored at the two ends, at one end, or not at all.

The boring shall be done in the boring mill, in conformity with the tracing, which shall be sent to the contractor, and which the company, moreover, shall have the right to modify in the course of execution (of order). The rails of 16 m and above shall in addition have two holes bored at or near the center of their length in accordance with the drawings furnished by the company.

The holes may be oval; they shall have the burr completely removed. Each rail in which the boring of the holes is not exactly in conformance with the tracing and templets furnished by the company shall be rejected. A tolerance of 0.5 mm (0.0005 m) shall, nevertheless, be accorded in the position of the holes.

8. Testing.—The rails shall be divided with care at the factory into groups by heats, coming from the manufacture of one or several days, and the rails not bearing the number of the heat shall be rejected. The agents shall choose in each series a certain number of rails, 1 per cent or more, which shall be subjected to the following tests.

Transverse Bending Test.—Each of the test rails placed horizontally on two supports at a distance of 1.10 m apart must be able to support for five minutes at the center of the span (*1*) without suffering any permanent deformation after the test, a load of 30 000 kg for the rail type 46k and 18 500 kg for the rail type 36k; (*2*) without bending at the center more than 25 mm, a load of 50 000 kg for the type 46k and 35 000 kg for the type 36k.

The load is then to be increased to destruction for informatory purpose, the deflections being measured during the test. Each of the two halves of the test piece so broken is then to be placed horizontally in the impact testing machine. The latter must have an anvil of 10 000 kg weight, and this must be set in masonry at least 1 m high and with an area of base of 3 square meters at least. The specimens are supported with a span of 1.10 m. These rail pieces must then withstand without breaking the blow of a hammer of 600 kg for the type 46k and 300 kg for the type 36k falling from a height of 5 m onto the center of the rail span.

With fall of.....	1 m	1.50 m	2 m	2.40 m	3 m	5 m	Type of rail	Hammer
	mm	mm	mm	mm	mm	mm	k	kg
The deformation must not be as great as.....		7	18	.....	35	60	46	600
Nor much greater than	4	5	12	18	.....	35	36	300

If one of the test pieces breaks under a fall of less than 5 m, the test will be carried out with a greater number of the rail bars, and if of these more than one-tenth do not pass the tests the whole series shall be rejected.

From each series of rails, grouped as has been described at the commencement of the present article, one may be taken, from the head of which a tensile test piece shall be cut cold. The piece turned from this rail shall be 10 cm in test length and 13.8 mm in diameter, and must have an ultimate tensile strength and elongation, which are given by the following equation

$$R+2A=92$$

where R is the tensile strength in kilograms per square millimeter and A the elongation in per cent. Moreover, the former may not be less than 65 kg per square millimeter nor the latter less than 10 per cent.

If any one of the above tests is not satisfactory, they may all be repeated on other specimens, but if one of these latter tests is not met, the lot may be rejected.

In the same way tensile test specimens are to be taken from the web, which shall be 10 cm long and 10 by 8 mm in cross section. Tests on these are to be made for the purpose of study.

Further, from a discard from one of the last rails and one from the first rails of each heat a specimen shall be taken which is at least 31 cm long and sent to the agent of the company. Tests made on these specimens are for the purpose of information only, and may not be made the basis of a rejection of the material.

9. Provisional Acceptance.—The provisional acceptance shall be made at the factory or mill by one or several agents of the company; it shall take place, as far as possible, concurrent with the manufacture, and its purpose shall be to weigh and stamp all of the rail bars satisfying the stipulated conditions.

The furnishing of the testing apparatus, as well as the labor necessary for the inspection and testing done for the purpose of obtaining assurance of the quality of the steel and of the good manufacture of the rails shall be at the charge of the contractor.

The rail bars accepted shall be stamped at their two extremities; those rejected shall in the same way be marked with a special mark at the two extremities, which shall be easily visible and indelible, in order that they may not be again presented for acceptance.

10. Guarantee.—The contractor guarantees the rails during six years, in which they are employed in frogs or in ordinary track, starting with the date of their manufacture.

Every rail which during that period shall break or crack or deteriorate in a manner other than that of ordinary wear shall be returned for replacement by the contractor.

In any case, in order to avoid heavy maintenance and transportation charges, the defective or broken rails, which may be utilized after recutting, may be kept by the company, it being understood that the contractor in that case shall only have to replace in rails of normal length the tonnage of the discards so made, and that the discards remain the property of the company, thus taking account of the expense of cutting and boring of the short rails obtained.

The new rails delivered in replacement, in application of the guarantee, must satisfy all of the conditions of the present specification; they shall be accepted provisionally at the factory and delivered at the place indicated by the order in the maximum period of one month after each return of rejected rails; they are not to be subjected to a new guarantee.

11. Right of Surveillance.—The contractor shall give free access to his shops to the engineers and agents of the company, who shall make the verifications necessary to determine whether all of the conditions of the present specification are being exactly fulfilled.

12. Responsibility of the Contractor.—The surveillance exercised by the engineer and the agents of the company at the factory of the contractor, the verifications or

tests, the provisional or partial acceptances of the rails as manufactured shall not have in any case the effect of diminishing the responsibility of the contractor; this responsibility remains full and entire until the expiration of the period of the guarantee provided in article 10.

13. Subletting of Contracts.—It is formally forbidden the contractor to cede to other contractors or to have manufactured in other factories than his own any portion of the contract which is the subject of the present specification, without the express, formal, and written permission of the company.

SPECIFICATIONS FOR STEEL AXLES FOR CARRIAGES AND FREIGHT CARS, NO. 31 M P (1905)

CLASSIFICATION.—One class.

MARKS.—Each axle bears the marks or stamps indicated in the drawings and in particular:

(1) The mark of the contractor.

(2) The number of the month and the two last digits of the number of the year of the manufacture.

(3) The number of the heat from which it comes. The use of stamps with sharp corners or edges for the marking of the axles is forbidden.

MANUFACTURE.—The axles shall be of steel ingots of basic Martin steel, but the company reserves the right to use acid steel of the same furnace if it receives guaranties of the quality of the scrap iron used in the charges. The use of charges of pig in the furnace which contain more than 0.1 per cent of phosphorus is forbidden. Each ingot shall furnish at least two axles.

The ingots are forged under a hammer of at least 10 metric tons weight or hydraulic press of appropriate power into a round which shall have a section not greater than one-fifth of its original one. In the course of that operation all seams, scale, or other surface defects, which detract from the quality or appearance of the axle, shall be removed with the chisel, hot or cold.

Each bar of this sort shall be completely free from all spongy parts from the top or bottom of the ingot and from traces of the pipe. The axles shall correspond in their finish and dimensions to the specifications and sketches, and where called for shall be ground and polished.

The axles shall be forged down before any work of machining until the diameters be within 15 mm of those of the finished axles.

The forged or rolled (ébauchés) axles shall be centered with care, and the centers shall have, after turning the axle to its final length, a depth of 15 to 20 mm, corresponding to the designs.

APPEARANCE.—The axles shall be perfectly forged, and shall present in all parts sound surfaces, free from fins, fissures, discontinuities, cavities, or other flaws.

REPAIRS.—Any trace of any repairs, with hammer or chisel, made with the purpose of masking flaws shall be a sufficient cause for rejection. The inspecting agent may authorize the repair of small superficial flaws, which he deems of no importance as regards the serviceability of the axle.

ANNEALING.—The axles must be annealed after their forging.

TOLERANCES ALLOWED IN THE DIMENSIONS—BODY.—The diameter may not be any smaller than the specifications call for, but there is allowed an excess of 3 mm.

There may, after centering, be no departure from the circular cross section in the parts which are not to be machined greater than 2 mm.

OTHER PARTS OF THE AXLE.—Forged axles (Bruts de forge) in the rough. The excess of metal, with respect to the dimensions of the finished axle, shall be (the axle being centered): In the diameters and fillets, at least 5 mm and at most 15 mm; in the total length of the axle, at most 5 mm at each end. No deficiency in length is permitted.

ROLLED AXLES (ÉBAUCHÉS).—The excess of metal is indicated in the designs and shall be such that the axle may be machined down to the finished dimensions without lack of material.

FINISHED AXLES.—The dimensions must be exactly those of the sketches.

Nature and Proportion of the Tests.—The axles are to be presented after the annealing for the tests in lots of 50 or less, all of which must be from the same heat but may be of different types.

Each axle shall have at both ends an excess of length sufficient for the obtaining of the specimen for the fracture test below.

NATURE OF THE TESTS.—The tests to which the axles shall be submitted are the following:

One axle from each lot (see above) or, at the will of the company, any fraction of a lot must be subjected to a drop test of the journal and of the body of the axle and to a tensile test.

A fracture test must be made on each finished or rolled axle presented. There may be made further a chemical analysis of each heat to determine the content of phosphorus, which may not exceed 0.07 per cent.

The inspecting agent chooses and stamps, in each lot presented, the axle destined for the drop, tensile, and chemical test.

TAKING OF THE TEST SPECIMENS.—For the purpose of the tensile test a bar is taken after the impact tests on the journal and body of the axle from the part least damaged by this test and at the surface of the axle. This bar is to bear at each end the stamp of the company.

The tensile test pieces must be cut out cold and similarly prepared for the test, and no operation of hammering, quenching, or annealing shall be used in the preparation of these test specimens.

Methods of Test and Results.—The results indicated below are the absolute minima allowed. Each test which is not passed is a sufficient cause for rejection of the corresponding lot.

DROP TEST—APPARATUS.—See No. 21 M P, page 60.

PREPARATION OF THE SPECIMEN.—Each axle chosen for the test must have the wheel seat rolled and the journals and collars turned to the required profile.

METHOD OF TEST.—The axle is placed horizontally under the impact testing machine with the wheel seat next to the journal to be tested resting on a support fixed to the base, the other wheel seat being held by a metal mass of at least 2000 kg in weight. The hammer of weight (if the weight differs a little from this, the inspecting agent shall change the height of fall in such a manner as to obtain a constant product of kilogram-meters) 500 kg is allowed to fall on the head of the journal twice in succession. The intensity of the blow struck shall be proportioned to the dimensions of the journals, and can be calculated from the following formula:

$$P\,H = 0.00054\,D^2\,L,$$

in which P represents the weight of the hammer in kilograms, H the height of fall of the hammer in meters, D the diameter of the journal in millimeters, and L the length of the journal in millimeters. The axle is then turned through 180° and subjected to two blows, the intensity of which is to be calculated from the following equation:

$$P\,H' = 0.00060\,D^2\,L.$$

Results.—The two journals must withstand the two blows of the hammer without fracturing or fissuring. The journals are then notched and broken (in the same way) and the fracture must be of a fine grain, homogeneous, and without flaws.

TESTING OF THE BODY OF THE AXLE—METHOD OF TEST.—After the breaking off of the journals the body of the axle, rough, is placed horizontally under the impact

hammer on two supports, at a distance of exactly 1.500 m in such a manner that the hammer strikes at the center. This hammer shall weigh 1000 kg (if the weight differs a little from this, the inspecting agent shall change the height of fall in such a manner as to obtain a constant product of kilogram-meters).

In order to measure, after the first bending, the elongation in per cent of the most stressed fiber, the official of tests shall mark off with a punch 200 mm, half to the right and half to the left of the axis of flexure along the lower generating line of the body of the axle.

The axle shall then be struck two blows successively with the hammer. The intensity of the blows shall be proportioned to the dimensions of the axle and shall be calculated from the following formula:

$$P\,H=0.35\,D^2,$$

in which P and H have the usual significance and D represents the diameter at the center of the body of the axle in millimeters.

Having determined the elongation of the most stressed fiber, as described above, the axle is to be turned around in the opposite direction and straightened with two blows of which the intensity can be calculated from the following formula:

$$P\,H'=0.40\,D^2.$$

The test is repeated by resubjecting the body to the same process, with the latter intensity of blow.

Results.—The body must support the four above tests without breaking or showing cracks.

The elongation in per cent over the 200 mm mentioned above must fall within the limits 9 to 13 per cent.

TENSILE TESTS.—The test piece taken as described above shall be cylindrical.

For form, marking, dimensions of the test pieces, duration, and temperature of the test, see No. 21 M P, page 61.

Results.—Axles for carriages and freight cars shall have at least a tensile strength of 45 kg per square millimeter and an elongation of 25 per cent.

FRACTURE TEST.—At each end of each axle, forged or finished, a round bar is taken in the part forming the excess length. These round bars are obtained by a cut on the lathe at the appropriate distance, and such that the cylindrical base of the notch so made concentric with the outer circle of the axle shall have a diameter at least equal to 45 mm.

The round bars shall be detached by impact in the presence of the inspecting agent.

The fracture shall show a fine grain without flaw or sponginess.

SPECIFICATIONS FOR STEEL TIRES FOR LOCOMOTIVES, TENDERS, CARRIAGES, AND FREIGHT CARS, NO. 21 M P (1906)

1. General Conditions.—CLASSIFICATION.—The tires for locomotives, tenders, passenger and freight cars are divided into four classes, A, B, C, and D.

MARKING.—Each tire bears the following marks on the outside face: The number of the heat, the trade-mark of the factory delivering the tires, the date, and characterization of the material, and other marks in accordance with the requirements or designs. These marks are stamped hot, deep enough, and as near as possible to the interior circumference, in order that they may not be removed by the machining.

MANUFACTURE.—The tires shall be made of basic Martin steel, although, when it finds sufficient guarantee of the quality of the scrap used in the charges, the company reserves the right to use the acid steel. The use of charges containing more than 0.1 per cent of phosphorus is forbidden.

The ingots are to be completely freed by one means or another of all spongy parts from the top or bottom, and of any trace of the pipe (poche de retassement).

The ingots are forged with the steam hammer into rings, which after cleaning are rolled into the profile desired.

APPEARANCE.—The tires must be sound in all respects, may not show seams, cracks, blowholes, fins, scale, or repairs (crique, gerçure, soufflure, paille, bavure, reprise), nor any flaw which would interfere with their use.

REPAIRS.—Any trace of repair work with the hammer or the chisel having for purpose the covering up of defects of any sort is cause for rejection.

The purchasing agent may have small surface defects, which he adjudges to be without effect on the service qualities of the tires, repaired.

ANNEALING.—The tires must all be annealed.

TOLERANCES IN THE DIMENSIONS.—The following tolerances only are allowed:

(1) *Diameters:*

Specified interior diameter	Interior diameter, rough	Exterior diameter
0.92 m	+0 −3 mm	−0 +4 mm
1.20 m	+0 −4 mm	−0 +5 mm
1.20 m	+0 −5 mm	−0 +6 mm

(2) *Widths:* −0 +2 mm.

Ovalization, eccentricity, and coning are limited to 2 mm per meter, whatever the diameter of the tire.

2. Nature and Number of the Tests.—The tires shall be presented for test after annealing and for this purpose shall be grouped into lots, of which all are from the same heat, but may be of different types.

NATURE OF THE TESTS.—One tire of each heat for the types A, B, and C shall undergo a drop test and a tensile test. One tire of each lot of the type D shall undergo a flattening test under the hydraulic press, followed by an impact test.

There may be made, further, a chemical analysis of each heat, and the content of phosphorus shall not be more than 0.07 per cent.

The inspecting agent shall choose and stamp, in each lot presented, the tire destined for the test.

3. Preparation of the Test Samples.—The tensile test specimen is to be taken from the samples tested in the impact machine, and shall be taken from the part least damaged by the previous test and as near as possible to the reamed surface (surface d'alésage). The place where the piece is to be taken is marked, traced, and stamped at the direction and under the care of the inspecting agent.

The cutting of the test specimens should be done entirely cold, on the lathe, with the saw, etc.

The work of the preparation of the test specimens as taken, shall also be done cold, on the lathe, without any operation of hammering, quenching, or annealing.

The test bars shall have at each end the stamp of the railway company.

4. Method of Test and Results to be Obtained.—The values given in the following are the absolute minima allowed, and a lot which does not give at least these values may be rejected.

DROP TEST—APPARATUS.—The drop test is carried out with a fall hammer, which falls in vertical guides, which shall be absolutely rigid, plane, and vertical, and arranged in such a manner that the tup falls with a minimum of friction. The center of inertia of the mass of the hammer shall be as low as possible and at the exact center of the vertical guides and the tup shall have a mass and form symmetrical to the plane of the guides. The hammer guides shall be much longer than the width of the hammer. The release of the hammer shall operate without interfering with its free fall. The hammer face shall be the surface of a cylinder whose axis is horizontal and lies in the plane of the hammer guides. The radius of this surface shall be not greater than 10 cm and the development of the cylindrical part of an angle of 90°.

The base or anvil consists of an incompressible mass which is at least 15 times as great as that of the tup, and in case it is embedded in a mass of masonry the metal part shall have a weight of not less than 10 000 kg.

METHOD OF TEST.—The tire for test is chosen by the inspecting agent and tested in the condition in which it is to be delivered. The tire placed in position on the anvil receives on the topmost part the successive blows of a hammer of weight of 1000 kg (if the weight differs a little from this value, the inspecting agent shall change the height of fall in such a manner as to obtain a constant product of kilogram-meters) falling from a height of 10 m. This height is determined by the thickness of the tire at the tread circle, and the above value holds for a thickness of 65 mm at this point. For each millimeter of difference the height is increased or diminished by 0.07 m.

Results.—The tires must support without breaking or even cracking—for type A, 2 blows; for type B, 3 blows; for type C, 6 blows.

The test may be carried to destruction with or without notching.

The fracture must show a fine grain, uniform, dense, and without flaws of any kind.

TENSILE TEST.—The test specimen shall be taken as noted in section 3, and shall be cylindrical with test heads.

FORM OF SPECIMENS.—The heads of the test specimens may be adapted to the grips of the testing machine, but no stresses in the axis of the test piece may be introduced by any such method of gripping, such as with eccentric head, etc.

For the measurement of the elongation, marks shall be made on the specimen, whose distance apart shall be given by the formula

$$L=\sqrt{66.67\,S}$$

where S denotes the area of the section.

These marks are crosses which begin at the fillet. The fraction of the length between these marks, which serves for the calculation of the elongation in per cent, shall be that which contains the section of fracture.

Dimensions are recommended for these specimens as follows:

Diameter	15.96	mm
Section	200	sq mm
Test length	147	mm
Distance between marks	115	mm
The fillet at the head shall be of radius	10	mm

DURATION AND TEMPERATURE OF THE TEST.—The test shall be by progressive loads and take between one and six minutes, depending upon the volume of the test piece, and shall be made at the ordinary temperature.

Results.—Minima allowed:

Type	Ultimate	Elongation
	Kg/mm²	Per cent
A	60	18
B	70	14
C	70	14

FLATTENING TEST UNDER THE HYDRAULIC PRESS, FOLLOWED BY THE DROP TEST—PREPARATION (FOR TYPE D ONLY).—The tire is reamed (alésé) until the thickness of the tire at the tread circle is reduced to 55 mm.

METHOD OF TEST.—The tire is then subjected to the action of a compression testing machine. The load is applied at the two extremities of the same diameter

by means of wedges of a height of 20 cm, which follow the outline of the tire and tends to flatten the tire. This machine shall have separate devices for the application and for the measuring of the load and deformation.

It must be possible to apply constantly increasing loads without shock, and the load may not be applied eccentrically (to the diameter of the tire).

The surfaces of the supports shall be of a metal which is hard and will not fail under the loads applied, and the measuring device must be as simple as possible in order that its maintenance and calibration may not be difficult and must measure the actual applied load of the machine without regard to friction of the machine, lost motion, etc.

The tire shall be flattened by 17 per cent of its original diameter. The load necessary to produce this deformation shall be at least equal to that calculated from the following formula:

$$P = 15{\cdot}334{\cdot}355 \frac{I}{D}$$

in which P is the pressure expressed in metric tons; I, the moment of inertia of the tire section with respect to an axis through its center of inertia and parallel to the axis of the tire; and D is the diameter of the tire after reaming; all of the elements entering into the dimensions are expressed in meters.

Results.—The tire tested may not break or even crack under the test mentioned.

TEST TO FOLLOW.—The tire tested in the preceding manner shall then be placed with its elongated diameter vertically in the impact machine and is there subjected to three blows of the 1000 kg hammer.

The height of fall of the first two blows shall be 10 m, and that of the last sufficient to reduce the vertical diameter of the tire to 83 per cent of its original value (before the tests).

Results.—The tire must withstand this test without fracture or fissuring. This test is to be also carried to destruction, and the fracture must be uniform, dense, and without flaws.

SPECIFICATIONS BY LETTER FROM THE CHIEF ENGINEER OF THE FRENCH EASTERN RAILWAY (1913)*

Tires.—No part of the tire shall be heated to a temperature greater than 400° C, in order to preserve the structure given to the metal by the heat treatment at the factory. (This refers to the shrinking on of the tires.)

SPECIFICATIONS, NO. 39 M P, FOR WHEEL CENTERS OF CAST STEEL (1907)

1. The present specifications relate to wheel centers of cast steel, rough, rolled, or finished as indicated in the order.

MARKING.—(Here omitted.)

MANUFACTURE.—The steel used in the manufacture of wheel centers shall be either Martin or crucible steel. The use of pig in the charges which contains more than 0.1 per cent of phosphorus is forbidden.

ANNEALING.—All of the wheel centers shall be annealed. The success of the annealing shall be determined by the examination of the fracture of the discards, which must be uniform, free from crystalline facets and ingotism, and it must be possible to obtain with a cold tool chips or drillings as in the case of ordinary steel forged or rolled, and not quenched.

APPEARANCE.—The rough castings must be perfectly cleaned, and the oxide from the annealing must have been entirely removed. The rim must be uniform, and any part distorted by the annealing or tempering shall be roughed into position (degauchies). The wheel centers shall present no traces of the juncture of the mold, shall be free from fissures and (tapures) blisters, (gouttes froids) pipes; traces of burning should

be not extensive or important enough to interfere with the proper functioning of the wheel. The company shall be the judge of whether flaws of this sort found in the material shall be a basis for rejection. The articles shall be delivered without painting with any sort of paint.

REPAIRS.—Any traces of repairs made with a view to covering up flaws shall be a sufficient cause for rejection, but the agent of the company shall reserve the right to have repaired small surface defects which, in his opinion are unimportant.

The mode of repairing to be used in such cases must be approved by the chief engineer of the railway company.

TOLERANCES ALLOWED IN THE DIMENSIONS.—The finished parts must have the dimensions given in the specifications; on the other parts the following tolerances are allowed. For any point of the plate either parallel to the axis of revolution or in a radial direction, 2 mm; for other dimensions, 10 per cent, except that the actual margin in this latter case is not allowed to exceed ± 5 mm.

Tolerances in the weight of the wheel centers of the following amounts are allowed:

	Carriages, cars, tenders	Locomotive
	Per cent	Per cent
Rough wheels	− 3	−2
	+10	+8
Finished or rolled wheels	− 3	−3
	+ 7	+5

2. Nature and Distribution of the Tests—NATURE.—The tests which are to be carried out are drop and tensile tests on test pieces; bending, expanding, and equilibrium tests on the wheel centers themselves. There may also be made an analysis to determine the content of phosphorus, which may not be greater than 0.07 per cent.

NUMBER OF TESTS.—On the samples there may be made one drop and one tensile test for each heat.

On the wheels themselves there may be made one bending test on every 100 wheels for all the wheels, and one hub bore expanding test on one of every 100 of the simple wheels (roues simples) only.

The equilibrium test (for simple wheels only) is to be made on every finished wheel, and on one out of every 50 wheels which are to be furnished in the rough.

One phosphorus determination on every heat shall be made.

At the will of the company any fraction of a lot may be treated as a whole lot.

3. Taking of the Samples and Preparation of the Tests—TAKING OF THE SAMPLES.—The test bars shall, at the choice of the manufacturer, be taken from the least damaged parts of the wheel centers used in the resistance tests or from the better part of the discards of the castings after annealing.

The taking of samples from separate test ingots is only in exceptional cases allowed, and then they must be cast and annealed in as far as possible the same manner as the wheel centers themselves and in the same furnace.

The bars are to be cut out cold and shall not be subjected to any work other than that of cutting out and machining. The specimens taken from the already tested wheels, and which have been deformed less than 2 per cent, shall be cold straightened, those which have been deformed by more than 2 per cent may be straightened hot in the presence of the inspector before testing, as may also the test bars for the drop test. Otherwise no heating may be done. Even in the former case the temperature may not be greater than a dull red.

The shoulders of the test specimens for the drop test shall be lightly rounded with the file without sensible fillet.

PREPARATION OF THE WHEEL CENTERS FOR TEST.—The samples for the resistance tests shall be rough machined to within 2 mm of the finished dimensions, for the rim and length of hub, and the bore of the hub shall be reamed to the finished diameter. For reasons of economy the wheels taken for these tests shall be from those which from some small defect of form are unfit for service.

The test wheel centers and bars shall bear the stamp of the railway company.

4. Methods of Test and Results to be Obtained.—The values given below are the absolute minima, and failure to equal these values is sufficient cause for rejection.

TENSILE TEST.—(Form of test pieces, marking, dimensions, duration of the test, and temperature of the test, see No. 21 M P, p. 61.)

Results.—The tensile test specimens must show the following physical properties for the types of material M 1 and M 3:

Category	Tensile strength	Elongation
	kg/mm²	Per cent
M 1	40	20
M 3	45	15

DROP TESTS ON THE TEST BARS.—These test bars are machined to a cross section of 30 by 30 mm and a length of 200 mm.

METHOD OF TEST.—Each bar supported on edges 160 mm apart, which are fixed in an anvil weighing at least 500 kg, shall withstand the blow of a 50-kg hammer falling from a constant height of 3 m upon the center of the bar.

The striking surface of the hammer shall be part of a cylinder of radius 15 mm. developed through 90°.

The bar receives a first blow, is then turned through 180° and receives two more blows, after which it receives two blows alternately in each position until rupture.

Results.—The bar must withstand without fracturing or showing signs of cracks (counting the straightening blow) three blows at least for material shown by the tensile test to belong to the category M 1, two blows at least for material M 3. The test is then carried to destruction.

TESTS ON THE WHEELS—BENDING TEST.—The wheel center after being rough machined and reamed is placed flat on a ring support at the rim, and the hub is deformed by pressure or impact until the upper face of the hub is lowered by 4 per cent of the diameter of the rim.

Results.—During this test there should be no cracks, fissures, nor other evidence of failure produced. No account shall, however, be taken of such fissures, etc., as are formed in spokes or ribs and not ending at the hub.

After the first test the hub shall be broken off from the spokes or ribs either with a hammer or press or by any other method if fracture can not be obtained in this way. The fracture must be of fine grain, dense, uniform, and without flaw.

EXPANDING TEST (ONLY FOR SIMPLE WHEELS (ROUES SIMPLES)).—The hub is expanded, after being detached as indicated above, and starting from the bulged side, when the type permits, by the successive introduction of punches of conicity 1:100, until the inside diameter on the side from which punch was introduced has increased by 5 per cent.

Results.—This test must develop no cracks or evidences of failure. The test is carried to destruction, and the fractures must be homogeneous, of fine and regular grain, and free from sponginess (soufflure).

EQUILIBRIUM TEST (ONLY FOR THE SIMPLE WHEELS).—If the contract calls for wheels delivered unfinished, 1 of every 50 shall be turned and reamed for this test.

Method.—The (balourd) weight eccentricity shall not be more than 250 gr at a radial distance of 50 cm.

SPECIFICATIONS, NO. 41 M P, FOR WHEEL CENTERS OF THE PLATE TYPE, WITHOUT SPOKES OR RIBS (1904)

1. General Conditions.—The present specifications relate to single plate wheels of iron or steel, forged or rolled, rough machined or finished.

These wheel centers may have (1) plane or (2) curved plates.

MARKING.—Each wheel center must bear in the positions indicated in the drawings the following marks: (1) The mark of the manufacturer or contractor; (2) the number of the heat if the latter are numbered; (3) the month and year of manufacture (the latter being indicated by the two last numbers); (4) all other marks demanded by the railway company. The letters and figures shall be easily legible and shall have a height of at least 12 mm. The use of stamps having sharp edges is not permitted.

MANUFACTURE.—These wheel centers shall be made by forging or rolling cast steel, free from pipe or blow holes (soufflure), and of good quality, from open hearth or converter. The metal shall be such as to be easily machined.

ANNEALING.—The wheel centers shall be annealed.

APPEARANCE.—The parts which are not to be machined shall be well cleaned, without mold seam; the rim shall be uniform. The parts deformed by shrinkage or the annealing shall be suitably roughed into shape.

The wheel centers shall be free from cavities and fissures; the fins, cracks, and other flaws shall not be of importance from the point of view of the use of the wheels. The company is the judge of the acceptance of wheel centers showing such flaws.

REPAIRS.—Any trace of repair work done for the purpose of covering up defects shall be a cause for rejection, although the agent of the company reserves the right to have small superficial repairs made.

DIMENSION TOLERANCES.—The parts to be finished for mounting adjustment must correspond exactly to the diagrams.

The remaining parts shall have no point in the plate displaced from its normal position more than 2 mm, and the thickness shall have no greater variation from that specified at any point than -2 mm or $+3$ mm.

Variations in weight are allowed, for rough wheels, of -3 or $+5$ per cent; for finished wheels, -3 or $+4$ per cent.

2. Nature and Distribution of Tests.—The tests to be carried out on the wheels themselves are (1) resistance tests (bending, expanding (hub)) and (2) equilibrium.

There may also be made a phosphorus determination on steel wheels, and the phosphorus content may not exceed 0.07 per cent.

PROPORTION OF TESTS.—(1) *Resistance Tests.*—One shall be made on every 100 wheels.

(2) *Equilibrium.*—One for 50 unmachined wheels, and on every finished wheel.

(3) *Phosphorus Determination.*—One for every heat. Any fraction of a lot may serve as a lot at the discretion of the company.

3. Taking and Preparation of Samples.—See 39 M P, page 63.

4. Methods and Results of Tests.—See 39 M P, page 64, except that the bending test should give a deformation of 2 per cent for iron and 4 per cent for steel wheels; the expanding test, an expansion of 3 per cent for iron and 5 per cent for steel wheels.

SPECIFICATIONS NO. 42 M P, FOR ASSEMBLED WHEELS FOR CARRIAGES AND CARS (1913)*

Mounting of Wheels and Axles—AXLES.—Dimensions and finishing.

CENTERS.—Dimensions and finishing.

TIRES.—Dimensions and finishing.

MOUNTING.—The pressure used in forcing wheel on axle shall be from 30 000 to 45 000 kg.

EQUILIBRIUM.—Equilibrium tests shall be carried out on mounted wheels. The balancing weights shall not be greater than 1 kg at the running surface.

[By letter from engineer in chief, September, 1913]

Mounting of Wheels on Axles.—A conicity of more than 1.5 millimeters per meter is not allowed in the wheel seat of axle.

Diameter of wheel seat	Mounting pressures
Millimeters	Kilograms
100–125	22 000–33 000
126–150	25 000–40 000
151–175	30 000–45 000
176–200	40 000–55 000
201–250	45 000–60 000

NORTHERN RAILWAYS

SPECIFICATIONS FOR STEEL RAILS OF THE TYPE VIGNOLE (1898)

Types of Rails.—The present specification has for its object the furnishing of rails of steel of the types in use by the Northern Railways Company.

These types are: Model 45k, of normal profile for track; model 43k, of special profile for the construction of track apparatus; model 30k, of normal profile for track; model 30k, of special profile for frogs.

The company will designate in the order and contract the types and the quantities of rails to be furnished, as well as the period of delivery and the conditions of the regulation of the delivery.

Profile of the Rails.—The rails shall be of the American profile, Vignole. The profile shall present exactly the form of the templet, stamped, which shall be sent to the manufacturer or contractor; it shall be rigorously adhered to over the whole length of the rail bars, and particularly at the extremities, where care shall be taken to avoid compressing or altering the section at the time of cutting.

In order to take account of the wear of the rolls, and of the precision, more or less, of their tightening, there shall be accorded a tolerance of 0.5 mm, plus or minus, in the dimensions of the transverse section, but the profile shall remain always perfectly symmetrical. The rails which within the limits indicated do not reproduce the form of the templet shall be rejected.

Length of the Rails.—The rail bars shall have the length designated in the table below, or those indicated. (The table of the lengths is omitted; these vary from 6 to 12 m.)

The company reserves the right to order rails of lengths above those indicated above up to 1/20 of the whole lot to be delivered.

There shall be accorded in the length of the rails a tolerance of ± 2 mm.

Kind and Quality of Material.—The steel for the manufacture of rails shall be Bessemer or other steel acceptable to the company.

The operations shall be conducted in such a manner as to obtain a material of the best quality with a fine, dense, and uniform grain.

The steels shall be in all respects in conformity with the specimen which shall be sent to the railway company by the contractor. The current manufacture of the rails shall not commence until this specimen shall have been accepted by the engineers of the railway company.

Ingots.—The steel shall be cast in ingot molds consisting of one piece. The form and dimensions of the ingots shall be approved by the engineer in chief of the company; this does not relieve the manufacturer of responsibility for his material.

The weight of the ingots shall be large enough to allow of obtaining discards sufficiently long to insure soundness in the rails.

The ingots shall be examined with care; those which show sponginess (soufflures), impurities, or other flaws which will not disappear during the rolling shall be rejected. Simple cavities as well as burrs (bavures) shall be removed from the surface with great care and over a surface sufficiently extended that it will render impossible the superposition during rolling of the walls of these cavities or burrs.

The agent of the company shall have an ingot broken whenever he judges it necessary to study the results of the manufacture. The fracture shall be free from blowholes. However, the total number of ingots so broken shall not exceed one five-hundredth of the whole number.

The inspector shall have the right to demand that samples of the steel shall be taken at the pouring of the ingots, and he shall assure himself of the quality of the steel by quenching and bending tests.

Manufacture of the Rails—Rolling.—The rolling shall be conducted in such a manner as to obtain the exact profiles of the rails with smooth and even surfaces and to avoid warping. Rails presenting flaws, fissures, etc., and all other faults of manufacture, shall be rejected.

All repair work, hot or cold, on the rails is forbidden.

Rails not fulfilling the conditions given above shall be rejected.

Marking.—The rails shall bear on the two faces of the web easily visible marks designating together the factory or plant, the year and month of manufacture, as well as the nature of the steel. These marks shall be in exact conformity as regards the form and the dimensions of the letters and the figures, the thickness and profile of the relief, with the drawings, which shall be sent to the contractor; they shall result from an engraving made in the last finishing rolls, with the exception of the number of the heat, which shall be applied after emergence from the rolls with a stamp. A rail which does not bear the heat number shall be rejected.

Cutting and Straightening of the Rails.—The rails shall be cut with the circular saw, after coming from the rolls, at a sufficient distance from the crushed ends that the two extremities are perfectly sound and in such a manner that that part which comes out first from the last roll and is habitually curved with a small radius shall be removed (made to disappear).

Afterwards the rails shall be straightened hot as much as possible on a platform of cast iron which is well leveled. They shall then be placed upon a well-ventilated frame platform solidly built.

Operations Done in the Cold.—The final straightening of the rail bars, necessary in order to remove the imperfections of the hot straightening, shall take place cold upon the four faces. This operation shall be executed gradually by pressure and not by blow or impact, in such a manner as to avoid all fissuring of the material of the rail; protecting pieces of convenient form shall guarantee and preserve the base.

Cutting to Length.—The final cutting to length shall be done cold, at the milling machine, or by any other method giving results equally perfect. The sections obtained in this way shall be perfectly plane and perpendicular to the axis of the rail. The burrs of these sections shall be carefully removed with the file; it is absolutely prohibited to clear them with a hammer. Cutting with the saw or shears by reheating of the ends is formally prohibited.

Boring and Grooving of the Rails.—The rails for ordinary track shall, according to the models, be bored and grooved, or only bored in conformity with the tracing which shall be sent to the contractor. In the case of rails of exceptional length the indica-

tions accompanying the order shall be followed. The cutting of the holes in the web, executed in the boring mill, shall produce holes perfectly cylindrical, and which are in accordance with the indicated diameters. The burrs of the holes shall be removed with the chisel and file. There shall be allowed a tolerance of 0.5 mm with respect to the prescribed positions.

Testing of the Rails (for the Normal Types 45k and 30k)—PRELIMINARY TESTS.—Each heat shall give one ingot heavier than the others, such that one rail can be obtained with an excess length of 1.50 m, the part crushed not being taken account of. There shall be cut off with the saw this crushed part, then at a second cut a piece of a length of 1.50 m shall be removed, which shall come from the upper part of the ingot and bear the number of the heat corresponding to the rail bar from which it was taken.

This piece of rail placed horizontally on two supports, distant 1.10 m apart, and reposing upon an anvil built according to the conditions indicated below (drop test) must support, without breaking the blow of a hammer of 300 kg weight, falling freely from a height of 5 m for the rails, model 45k, and of 3.50 m for the rails, model 30k. The amount of bending caused shall be 17 mm for the rails, model 45k, and 20 mm for the rails, model 30k. There shall be allowed a tolerance in that amount of bending of 30 per cent, more or less.

If the preliminary test is not satisfactory, a rail of the heat shall be subjected to the final tests of transverse bending, the drop and tensile test described below, and if these tests are not passed, the whole heat may be rejected. If, however, the test is satisfactory, the rails of this heat may be classed with the lot which are to be submitted to the final tests.

FINAL TESTS (EPREUVES DEFINITIVES).—The rails are to be divided with care at the factory into series coming from the production of one or several days. The agent of the company shall choose in each series for test purposes rails from different heats in the proportion of 1 per cent.

From each of the rails so chosen there shall be taken two pieces of 1.50 m in length coming from the top of the ingot; one of these is for the transverse bending test, the other for the drop test.

TRANSVERSE BENDING TEST.—One of the rail pieces, base up, is loaded at the center of a span of 1 m for five minutes—first, for model 45k rails with 36 000 kg, and for model 30k rails with 22 000 kg; then for model 45k rails with 50 000 kg, and for 30k rails with 32 000 kg—and must at the first loading show no measurable permanent set after the test and at the second a total set less than 25 mm.

The test is then carried to destruction.

DROP TEST.—The second end of the rail of a length of 1.50 m, placed horizontally on two supports at a distance of 1.10 m apart, fastened upon an anvil of cast iron of 10 000 kg weight, which itself rests upon a mass of masonry having a height of 1.0 m and an area of base of 3.30 m^2, must support without breaking the blow of a hammer of 300 kg weight falling freely on the rail bar at the center of the span, from a height of 3.50 m for the rail type 45k and 2.50 m for the rail type 30k, after having been bent the following amounts under blows of successive height as follows:

Height of fall:	1.50 m	2.00 m	2.50 m	3.00 m	3.50 m
Model 45k	4 mm	9 mm	15 mm	22 mm	30 mm
Model 30k	7 mm	18 mm	30 mm	.....	.....

A tolerance of ± 20 per cent is allowed in the amount of bending as given above. The amount of rebound shall give some idea of the elasticity of the material.

THE TENSILE TEST.—In each rail which has been subjected to the preceding tests there shall be taken cold from the rail head a machined test specimen, which shall be subjected to the direct tensile test according to the procedure indicated below. The test length of the bar shall be 200 mm, counting between the fillets at the heads; the diameter shall be 25 mm, corresponding to a cross section of about 500 $mm.^2$

The heads of the test bars shall have a form fitted to the tensile testing machine.

In no case shall these test specimens be annealed.

LIMIT OF ELASTICITY.—These bars shall be subjected to tensile stresses in order to determine the limit of elasticity of the metal; that is, the limiting load in kilograms per square millimeters of cross section under which the specimem does not suffer any permanent elongation. This limit of elasticity in the steels for the rails of the quality defined by the bending and drop tests, shall not be less than 38 kg per square millimeter. There shall be applied an initial load of 30 kg and maintained during five minutes. Additional loads are then applied at and during intervals equal approximately to five minutes; these additional loads shall be as nearly as possible equivalent to 1 kg per square millimeter of section.

There shall be determined the maximum load, at and below which the elongation is elastic; as soon as the least permanent elongation has been observed the operation shall be discontinued, and the elastic limit will be taken as that load immediately preceding that at which there was first noticed a permanent elongation.

The test shall then be continued to rupture, starting with a load of 55 kg per square millimeter of cross section, maintained for five minutes. Additional loads of 1 kg (per square millimeter) shall then be added up to the ultimate breaking load, as is described above. The load which shall have produced rupture shall be noted and the tensile strength calculated in terms of kilograms per square millimeter of original section. This ultimate strength shall not be less than 68 kg and the elongation shall be at least 8 per cent. The value of the quantity $R+2a$ (R, ultimate strength, a the elongation in per cent, measured on a bar of 0.200 m) shall never be less than 90.

After the rupture of the test bar there shall be determined as exactly as possible the reduced section at the fracture with respect to the original section in order to calculate the reduction of area.

The permanent elongation suffered by the test bar after rupture shall be measured over a total length of the bar of 0.200 m and shall be expressed by the formula: $a=\frac{100\,x}{200}$ (x represents the total elongation in mm).

If the profile of the types of rails does not permit of the tests of transverse bending and the drop test, only the tensile test shall be carried out.

For that purpose there shall be taken, from a rail bar from each heat and in the head, a test specimen, which shall be prepared and tested in the manner indicated above.

RESULTS OF THE TESTS.—These tests shall be made in the presence of all parties (contradictoirement). If the results are satisfactory, they shall be stated in a memorandum signed by the agent of the company, and the lot shall be accepted as far as the quality of the material is concerned.

If the results obtained on any one whatever of the tests were recognized as deficient, this test shall be repeated on the same proportion of rails taken in the same series (see above), and if the new test is not satisfactory in any particular, the lot shall be definitely and entirely rejected.

The company may, moreover, prescribe and have other tests of any sort carried out, which it may deem necessary for the purpose of assuring itself with respect to the quality of the rails.

In particular cases indicated by the engineer (of the railway company) there shall be taken a specimen of the material in the form of filings of the weight of about 10 grams, which shall be addressed to the central track material service, which will have it analyzed. The results of the analysis shall be noted as further information.

SURVEILLANCE OF MANUFACTURE.—The contractors shall allow free access, day and night, of the engineers of the railway company or their agents assisting to their shops and plant, to the different operations of the manufacture of the rails, and it shall be permitted the latter to make whatever verifications they may deem necessary for

the purpose of obtaining assurance that all of the conditions of the present specifications are being exactly fulfilled.

PROVISIONAL ACCEPTANCE.—(Here omitted.)

WEIGHT OF THE RAILS.—The normal weight per meter of the rail shall be determined at the time of the delivery of the first lots, on rail bars having a section perfectly in conformity with that of the templet.

The tolerance admitted above in the dimensions of the rails contains one of ± 2 per cent, fixed from the present time, in the normal weight for the partial deliveries. Below that tolerance the rails shall be rejected; above, they may be accepted, but in that case they shall be paid for according to the normal weight augmented by the tolerance, it being understood that the excess to be paid to the contractor is limited to 1 per cent of the whole delivery.

RESPONSIBILITY AND GUARANTEE.—The surveillance exercised by the engineers of the railway company and their agents at the factory and plant of the contractors the verifications and tests, the provisional acceptance of the manufactured rails shall not have in any case the effect of diminishing the responsibility of the contractors, which shall remain full and entire until the expiration of the period of the guarantee.

The contractors guarantee the rails during six years, beginning with the date of their manufacture, that they are employed in service. Nevertheless, there are excepted from that guarantee those rails which, because of their special destination or purpose, shall have been submitted to cold or hot operations by the company (railway). With this exception, each rail which during this period shall break or deteriorate, other than by regular wear, shall be replaced by the contractors under the conditions following. (The remainder is omitted, dealing with the actual shipment of replaced rails, the final acceptance, etc.)

SPECIFICATIONS FOR CRANK AXLES (ESSIEUX COUDÉS) (1908)

1. General Conditions.—Crank axles of forged steel are of three types, namely, ordinary Martin steel; Martin cannon steel, quenched in oil and tempered (annealed); nickel-chrome steel, quenched and annealed.

Marking.—The trade-mark of the contractor, manufacturer, the number of the heat, the date of the manufacture, and the type of the axle shall be stamped on the two extremities of the axles.

Manufacture.—The quality and mode of manufacture of the material shall be approved by the engineer in chief before execution of a contract.

The axles shall be delivered in the rough, rough machined, or finished in accordance with the indications of the order.

They must correspond as to form and dimension, finishing, and roughing of the different parts to the indications of the designs and order. They must have smooth sound surfaces, free from fins, cavities, folds, fissures, or other flaws. Any trace of repairs with hammer or chisel made with the object of covering up defects shall be a basis for rejection.

The agent of the company may, however, authorize small superficial repairs made which he adjudges of no importance as regards the serviceability of the material.

Heat Treatment.—The axles of ordinary steel (Martin) must be carefully annealed after forging; those of the cannon steel and of nickel-chrome steel shall undergo, after being rough machined, the heat treatment above mentioned.

Tolerances.—(1) FINISHED CRANK AXLES.—The dimensions shall be in exact conformity with those of the drawings.

(2) ROUGH MACHINED CRANK AXLES.—The excess of metal is indicated in the designs and in all cases it shall be sufficient that the finished dimensions of the axle may be obtained without lack of material.

(3) AXLES AS FORGED.—The excess of metal shall be such that the finished axle may be obtained without lack of material; in any case the weights of the axle as

forged must not exceed by more than 40 per cent the weight of the finished axle. The excess shall not be paid for.

Surveillance in the Factory.—The access to the factory or plant shall be accorded always to the agents of the company charged with the surveillance of the manufacture. The tests and the verification shall take place at the choice of the company in its own shops or in those of the contractor. The latter shall be obliged to furnish at his own expense the apparatus, the templets, calipers, etc., necessary for the inspection and tests.

When the operations shall take place in the shops of the contractor, the expenses shall be borne by him. In case the tests are carried out in the shops of the company the contractor is bound to ship at his own expense, and following the instructions of the inspecting agent, the test specimens taken by the latter.

The inspection in regard to the appearance and the dimensions not taking place but partially at the factory or plant of the contractor, every crank axle which shall be finally recognized as defective, or which does not have the proper dimensions in any particular, shall be refused and sent back to the manufacturer at the latter's expense.

The axles accepted provisionally at the plant of the contractor shall receive the mark of admission by the inspecting agent; those refused shall receive the special mark of rejection.

Right of Modification, Letting of Subcontracts.—The company reserves the right to modify the form or dimensions of the articles during the execution of the order, except that it must accept (subject to the usual conditions) pieces already manufactured according to the old dimensions. The contractors must furnish the new pieces of the type asked for without any indemnity except the difference in price, if any, between the old and the new pieces, estimated at the net cost (revient).

In any case the contractors may not sublet a part or all of the order without the authorization in writing of the company.

Even if this authorization is accorded, they remain entirely responsible for all of the parts of the order, just as if they had been manufactured in their own shops, and the company may send its agents into the plants of the subcontractors for the surveillance of the manufacture as into the plant of the contractor himself.

If the processes or the machines employed in the manufacture give rise to patent royalties, these shall be at the charge and expense of the contractors, who may not shift them to the company.

Tests.—The axles shall be presented after annealing or after quenching followed by tempering, according to the material in question.

The axles of ordinary Martin steel and those of Martin cannon steel shall have an excess length sufficient that at each of the ends a bar may be cut off which is 40 mm in thickness. The nickel-chrome axles shall have an excess length at one end sufficient to allow of the taking of a 250 mm sample. These shall be attached to the axle by a notched core only of a diameter of 40 mm, obtained on the lathe, or by a plate of 10 mm in thickness obtained on the shaping machine, and shall be detached in the presence of the inspecting agent. The work necessary in the cutting out of these cylinders shall not be done until after the operations of annealing or those of quenching followed by annealing (drawing of temper).

Taking and Preparation of the Samples.—There shall be taken in each bar (see above) of 40 mm thickness of the Martin steel, or cannon steel, two test specimens, one for the tensile test and the other for the drop test. In the 250-mm bars from the nickel-chrome steel axles there shall be taken two tensile test specimens, cut out longitudinally, and two specimens for the impact test in a similar manner. The places where the specimens are to be taken shall be traced, stamped, and marked under the instructions and supervision of the inspecting agent. The cutting out shall be done cold with the shaper, saw, or milling machine.

The work of preparing the samples for the test shall also be done cold without any operations of hammering, annealing, or quenching. The test specimens shall bear at their extremities the stamp marks of the company, and the shoulders at the heads of the test specimens shall be smoothed with the file without appreciable fillet.

TENSILE TEST.—The test specimens are to be cylindrical with test heads. The dimensions recommended are the following: Test length, diameter, 15 mm; length, 100 mm.

The results to be obtained are the following (minimum values):

Material	Ultimate tensile strength	Elastic limit	Elongation
	kg/mm²	kg/mm²	Per cent
Ordinary steel, transverse-cut specimen	45		20
Cannon steel, transverse-cut specimen	50		20
Nickel-chrome steel, axially-cut specimen	65	45	18

DROP TEST.—The bars for the drop tests shall have a section of 30 by 30 mm and a length of 250 mm.

Each bar placed horizontally on two knife-edges with a span of 160 mm, which are fixed in an anvil weighing at least 400 kg, shall support the blow of a fall hammer of weight of 25 kg falling freely upon the center of the span from a height of 2 m in the case of the ordinary or cannon steel, and of 3.50 m in the case of the nickel-chrome steel.

The striking face of the hammer shall have a radius of about 15 mm, developed through 90°.

The bars shall support without fracture or cracking 15 blows at least of the hammer, in the same position, i, e., without turning over.

Independently of these tests the company reserves the right to make other tests which it shall deem necessary for the assurance of the quality of the axles.

All lots of axles not satisfying the above tests shall be rejected.

Guarantee.—The crank axles shall be guaranteed to run 50 000 km in three years, at the most, and to run 100 000 km in total amount in less than four years; in other words, the price paid for a crank axle is never definitely acquired by the contractor until the axle has run 100 000 km.

Whenever an axle shall be retired from service because of rupture, cracks, or any other fault or cause before having made its run of the first guarantee of 50 000 km in three years, the contractor must deliver in replacement of the axle returned, another axle under the conditions of the contract and following the instructions which shall be given him. The company of the Northern Railways will refund the axle removed from service to the contractor at the price of the rough and unfinished axle, even when it was furnished finished originally, the expense of the machining resting with the railway company. The old material will be held at the disposition of the contractor, except such parts as the company wishes to retain as specimens or for test. If the return is demanded, the material will be sent collect.

When an axle is retired from service after a run greater than 50 000 km and less than 100 000 km in less than four years, the contractor shall be bound to replace the axle removed by another axle under the conditions of the contract, and following the instructions which shall be given him. The company will pay to the contractor a fraction of the price of the axle; rough, proportional to the run which it has made since being put in service, obtained by using 100 000 as divisor. In that case the expense of finishing shall rest, as in the first case, with the company, but the old axle shall be its property.

Every axle is considered as having made virtually a run of 50 000 km on the day upon which three years expires from the date of its delivery. The run made in the fourth year shall, according to the counting regulations, be added to a run of 50 000 km.

The value of the rough axle, deduction being made for the indemnity of the run, shall be subtracted from the debit of the contractor, following the instructions of the superintendent of material and traction.

The contractor shall be released from his contract four years after the delivery of the axle to the stores of the company.

The guarantee extends in the same way to the replacing axles.

SPECIFICATIONS FOR STRAIGHT AXLES OF STEEL FOR LOCOMOTIVES (1906)*

These are identical with those for the Paris, Lyon & Mediterranean Railways.

Guarantee.—These axles must cover a distance of 80 000 km in three years at most.

SPECIFICATIONS FOR STEEL AXLES FOR CARRIAGES AND FREIGHT CARS (1904)*

These are identical with those of the Eastern Railways.

Guarantee.—These axles must cover a distance of 80 000 km in three years at most.

SPECIFICATIONS FOR WHEEL CENTERS WITHOUT RIBS OR SPOKES (1911)*

These are identical with those of the Eastern Railways.

SPECIFICATIONS FOR RIBBED OR SPOKED WHEELS (1903)*

Where differing from the Paris, Lyon & Mediterranean Railways specifications it is indicated below.

One test per lot or per 100 pieces for weldability is required.

SPECIFICATIONS FOR WHEEL CENTERS OF CAST STEEL (1911)*

These are identical with those of the Eastern Railways.

SPECIFICATIONS FOR AXLES AND WHEELS FOR FREIGHT AND PASSENGER CARS*

Mounting pressure shall be at least from 30 000 to 40 000 kg.

STATE RAILWAYS

SPECIFICATIONS FOR STEEL RAILS OF THE TYPE VIGNOLE (1911)

1. The present specification concerns the delivery to the administration of State railways of steel rails of the type Vignole, EA, 1908, weighing 42.130 kg per meter.

2. All of the rails are of the same type, and differ only in their lengths and in the positions of the holes; the quantities of the rails of each length are indicated in the order.

3. Description of the Delivery to be Made.—(1) The profile of the rails of the type EA and the holes, etc., for each length are determined by the drawings sent to the contractor.

(2) The rails are of hard steel, of which the quality is defined in the article 4 below.

(3) There shall be accorded on the dimensions indicated by the drawings only the following tolerances: In the profile of the rails, those determined by the drawings of the templets sent to the contractor; in the length of the rails, at a temperature of 15° C, ±2 mm; in the position and dimensions of the tie-plate holes, 0.5 mm either greater or less; the verification of this shall be by means of templets of design furnished to the contractor in the diameter of the holes for the base plate, 0.5 mm plus or minus; in their position, 0.5 mm in the direction of the height and 2 mm in the direction of the length of the rails. The tolerances described shall, as a whole, be such that in any case the weight of the rails shall remain within the limits defined below.

NORMAL WEIGHT OF THE RAIL AND TOLERANCE.—At the beginning of the manufacture of the rails the normal weight per meter shall be determined by choosing and weighing 10 rails of great length from the first lot submitted for acceptance, and of dimensions as near as possible to those indicated by the designs.

There shall be accorded a tolerance of ±2.5 per cent in the normal weight, but the total weight of each partial delivery shall not be less than the normal weight by more than 1 per cent.

Outside of the limits thus fixed the deliveries may be refused.

Within the limit of that tolerance, for each partial delivery, the material shall be paid for according to its real weight up to the normal weight increased by 1 per cent; above that the excess weight shall not be paid to the contractor.

4. Quality of the Material.—The steel for the manufacture of these rails shall contain more than 0.3 per cent of carbon and less than 0.11 per cent of phosphorus.

To verify these analyses, the official of tests shall take from one or several of the heats, which make each of the series of 200 rails, and at the moment which he shall indicate, test samples, of a form indicated by him and of a weight not greater than 50 grams.

Two samples shall be chosen and stamped by the inspecting agent for each of the heats for which he shall have prescribed that analysis be made.

One of these samples shall be addressed to the State Railway Administration, which shall have it analyzed. The second shall be analyzed by the contractor. These two samples shall bear the number of the heat and shall be chosen in such a manner as will render them as far as possible comparable with each other.

The method used for the analysis at the plant shall be communicated to the railway administration. The series of rails may not be accepted until the results of these analyses are known, and the entire series shall be rejected if any one of the samples chosen does not have the required analysis. If one of the samples does not fulfill the chemical specification, the number of analyses is doubled by taking fresh samples from the same heats from which the first samples were taken which did not show satisfactory results. If the results of these analyses on the whole are not satisfactory in 50% of the cases at least, the whole series shall be rejected.

5. Manufacture.—The steel for the rails shall be exclusively Siemens-Martin, Thomas, or Bessemer. The company reserves the right to bar any method of manufacture which does not permit of obtaining a constant and homogeneous analysis, particularly in the matter of phosphorus. The process shall be conducted in such a way as to produce a fine, dense grain, uniform, and a material which will take a good quench.

THE INGOTS.—The steel shall be cast in ingot molds of one piece. The form of the latter is subject to the approval of the administration of State railways. The weight of the ingots shall be such as to obtain after rolling a discard of at least 1 m, without prejudice to the conditions in the following (see hot saws below):

One ingot of each heat shall be heavier than the others, and shall give an extra length of rail of 1.50 m to be used in the preliminary drop test described below.

ROLLING.—The rolling shall be conducted in such a way as to obtain the exact profile of the rails, with smooth and even surfaces, and to prevent any warping after coming from the last mill. The rails which show faults, discontinuities, fissures, scale, or other flaws shall be rejected. All repairs, cold or hot, of any kind are forbidden.

HOT SAWS.—After coming from the last rolls the rails are cut by the hot saw at the two extremities, at a sufficient distance from the crushed ends that the ends of the rail bar are perfectly sound, and in such a manner as to remove that part curved with a small radius which is habitually found at the end which emerges first from the last rolls.

STRAIGHTENING AND COOLING.—The rail bars should be quite straight over their whole length. They are straightened, after coming from the rolls, upon a cast-iron table, well leveled, and then placed for cooling upon a solidly-built platform (chassis). The hot straightening shall be done with care, such that the bending done under the cold presses shall be reduced to a minimum.

After cooling the hot straightened rails may not have a greater curvature than that of 4 mm in 1 m.

The final straightening is done cold by nonimpact pressure, and the span of the rail in the straightening press shall be at least 1 m.

FINISHING.—The finishing of the ends to dimensions must be done by milling or other equally good method; it shall not be done by the saw or shears with reheating of the ends. The ends of the sections shall be exactly perpendicular to the axis of the rails, and the burr of machining must have been removed completely with the chisel or file; under no pretext may the sections be finished (parées) with the hammer.

TIE-PLATE HOLES.—These must be drilled or milled and not punched, and are to be freed from the burr with the file.

MARKING OF THE RAILS.—(Here omitted.) Marking is required on both faces of web.

7. Preliminary Drop Test.—From that ingot of each heat made heavier than the others there is to be taken, immediately after the rolling, in the part coming from the top of the ingot, and following the crushed end, a piece of rail of a length of 1.50 m. This bar, resting on the base on two supports at a distance of 1.10 m apart, shall support, without breaking, the blow of a fall hammer of a weight of 600 kg falling from a height of 2 m onto the center of the span. The amount of bending is noted for the purpose of obtaining information, but there is no limit prescribed.

For this test the two supports are to be of cast iron of rounded angles and resting upon an anvil of cast iron of a weight of 10 000 kg, which itself is built onto a mass of masonry of 1 m of thickness (height) and having 3.3 m^2 of area of base.

If the piece of rail is broken, a rail of the same heat is subjected to the tests of transverse bending, the drop and tensile tests described in article 8, and if the rail does not entirely satisfy these tests, the corresponding heat is rejected.

If the rail piece is not broken, the rails of the same heat are simply included in the lots or groups, as is prescribed in the following article 8.

8. Final Tests.—The rails are to be grouped at the factory into series of about 200 rails, in such a manner that the rails from the same heat are all in the same group.

The official of tests shall choose one rail from each series, taken from the heats which have been analyzed. If one or several of the heats have given unsatisfactory analyses, there shall also be chosen one rail from each of such heats. From each of the rails so taken there shall be cut off a piece 3 m in length, which shall be subjected to the following tests:

TRANSVERSE BENDING.—*First Test.*—The rail placed horizontally upon two angular supports, at a distance of 1 m apart, shall support for five minutes a pressure of 30 000 kg at the center of the span, without becoming permanently bent more than 0.5 mm after the test.

Second Test.—The same rail bar, in the same position, shall support for five minutes a load of 48 000 kg without breaking or bending more than 25 mm under the load. The load is then increased until the rail breaks.

IMPACT.—Each of the broken halves from the above tests shall be tested in impact. Each piece placed horizontally upon two supports, distant 1.10 m from each other, must support, without breaking, the blow of a fall hammer of 600 kg, falling from a height of 2 m onto the center of the span of the bar. The permanent bending caused by this blow shall not be greater than 18 mm.

If either of the tests above is not passed satisfactorily, they are both to be repeated on two other rails of the same heat, and if these are not entirely satisfactory, the whole series shall be rejected.

TENSILE TEST.—From the head of the rail, from which have been taken the coupon serving for the preceding tests, there is to be cut cold a test specimen, which has in the machined part a test length of 100 mm, and a diameter of 13.8 mm.

This test specimen must support a load increasing progressively to the rupture of the bar; if R represents the ultimate resistance to rupture in kilograms per square millimeter of the original section, and A the elongation in per cent after breaking, these two quantities must satisfy the relation

$$R + 2A \overline{>} 92$$

The ultimate strength may not, moreover, be less than 68 kg per square millimeter and the elongation not less than 8 per cent.

If the tensile test is not satisfactory, the final tests of bending, the drop and tensile tests, shall be repeated upon another rail of the same heat, but upon two pieces of 3 m in length instead of one. If either of the last two tests is not entirely satisfactory, the entire series shall be refused.

9. Provisional Acceptance at the Plant.—(Omitted.)

10. Acceptance at the Place of Delivery.—(Omitted.)

11. Guarantee.—The contractor guarantees the rails during a period of six years, dating from the time when they are put in service. In any case, the period of guarantee shall not be greater than six and one-half years from the date of the last delivery of the lot made in the corresponding half year.

At the expiration of the period of the guarantee, the state of the rails to which it is applicable is investigated in the presence of all parties.

Every rail which, during that time, has become altered by any cause other than an accident or by the usual wear, is refunded or replaced by the contractor under the conditions given below.

(The further regulations dealing with the actual process of replacing the rails, or of refunding for them, are omitted.)

12. Delay in the Delivery.—(Omitted.)

13. Transport and Place of Delivery.—(Omitted.)

(These specifications have since been modified.)

MODIFICATION OF 1913.

The statement "Rails, Vignole, of steel, type EA, model 1908, weighing 42.130 kg per meter" is annulled and replaced by "Vignole steel rails, type EV, model 1911, weighing 45.520 kg per meter."

The paragraph dealing with the transverse bending test is annulled and replaced by the following:

TRANSVERSE BENDING TEST.—*First Test.*—The rail placed horizontally on two points of support of angular form, at a distance of 1 m apart, must support for five minutes at the center of the span a pressure of 32 000 kg without taking a permanent set of more than 0.5 mm after the test.

Second Test.—The same bar in the same position must support during five minutes a load of 51 000 kg without breaking or presenting an amount of bend, measured under load, of more than 25 mm. The load is then increased until rupture occurs.

The clause concerning the amount of bending required under the drop test is altered in the following way:

The permanent bending obtained with a height of fall of 2 m shall not be greater than 17 mm.

Article 13 is annulled.

PARTICULAR CONDITIONS.—The contractor shall have a specimen accepted before beginning the current manufacture of the rails.

The rails coming from the recutting of the rails of greater length shall be presented with the original holes (oval) at one extremity.

SPECIFICATIONS FOR STRAIGHT AXLES FOR PASSENGER AND FREIGHT CARS (1905)

(These are identical with those of the French Eastern Railways, No. 31 M P, p. 57.)

PARIS, LYON & MEDITERRANEAN RAILWAYS

SPECIFICATIONS FOR STEEL RAILS (1910)

The present specifications concern the furnishing of steel rails. (Several paragraphs deal with types of rail, lengths, design, dimensions, and weight which are not given in full below.)

The types of rails are the following: LP, 48 kg, main lines; PM–A, 39 kg, secondary lines; PLM2, 41.6 kg, special.

Tolerances are allowed of 0.5 mm in the section dimensions and from 1.5 to 2 mm in the length.

A margin in weight of ±2 per cent is allowed.

Manufacture.—The rails shall be of acid or basic steel, Martin or Bessemer, unless by special permit by the chief engineer of the company.

The process shall be conducted in such a way as to give the steel the best properties, a fine and uniformly dense grain, and it must be capable of being hardened well by quenching.

The current manufacture of the rails shall not commence until after the approval by the engineers of the company of the samples, which shall be sent by the contractor, in order that the former may judge of the nature of the grain of the steel and of the exactitude of the profile.

Carbon Content.—There shall be taken in each heat a specimen, which shall be forged in the shape of a bar 30 by 20 mm and which is to be subjected to a quenching test.

The inspector, whenever the quenching tests do not appear satisfactory to him, may, at all times that he deems appropriate, follow up these investigations in the following manner:

He shall have taken from all of the test specimens obtained in the course of the day one, which shall be stamped with a distinctive mark; the same day or in the evening he shall analyze this specimen in his laboratory, by the method of Eggertz or other similar method, with the purpose of determining the content of carbon. The next day, before 10 o'clock in the morning, he shall notify the factory of the result of the analysis. In case the analysis is contested, the operation shall be recommenced at the bureau, and under the care of the inspector, in the presence of the agents of the factory.

Whenever the proportion of carbon, thus determined, shall be less than 3 grams per kilogram, the heat having furnished the test piece, but only this heat, shall be rejected, and the ingots or the rails coming from it shall be grouped in such a manner that the factory may not dispose of them except in sight and with the knowledge of the inspector.

Ingots.—The steel shall be cast in ingot molds of one piece.

The ingots shall be of rectangular section with rounded angles and of dimensions acceptable to the engineer in chief.

The weight of these ingots shall be sufficient to obtain, after blooming, crops whose length is great enough that the pipes and blowholes have been removed.

The stripping of the ingots may not be begun until after a half hour from the time of pouring.

Structure of the Ingots.—An ingot may be fractured transversely or longitudinally, at the demand of the inspector, at any time deemed necessary in order to study the results of the process of the manufacture and to be able to judge of the size of the waste or crop which is necessary to demand; the number of ingots so fractured shall not be more than 1/2000 of the total number. In order to make the fracture, a notch may be made.

Rolling.—The rolling shall be conducted in such a manner as to obtain the exact form of the rails, with smooth surfaces, and avoid warping after emergence from the mills. Rails which show faults, discontinuities, cracks, repairs (reprises), fins, or all other faults of manufacture shall be rejected.

Straightening of the Rails.—These shall be as straight as possible as they come from the mills and shall be then straightened hot after coming from the last rolls on bed of cast iron and laid on a solidly supported rail bed to cool.

The final straightening, necessary in order to remove imperfections in the hot straightening, shall be done cold and gradually by pressure, without impact, in such a manner as to avoid causing fissures in the rail; appropriate shoes will be used to protect the flange and base.

Sawing and Finishing.—The rail bars shall be cut, at the hot saw, at the ends, at a distance from the crushed extremities sufficient that these ends shall be perfectly sound, and that the part coming first from the last rolls, and which is habitually curved with small radius, shall be removed.

The lengths at the ends of the rails cut off shall be at least 80 cm at the part corresponding to the top of the ingot, and 20 cm, to the lower part of the same.

The rail ends are finished properly at the milling machine or lathe; cutting with the saw or shears by heating is forbidden. This finishing of the ends shall be conducted in such a manner as not to alter the section at the ends.

The end sections shall be exactly perpendicular to the axis of the rail, and the burr formed by the machining shall be removed with a tool, chisel, or file; the use of the hammer is absolutely forbidden.

Boring of the Tie-Plate Holes.—These shall be bored or milled out and the burr removed with the file. A tolerance of 0.5 mm in the position of these holes with respect to the ones indicated in the drawings is allowed.

Repairs.—All repairs, cold or hot, are forbidden.

Marking of the Rails.—The rails shall bear on the two web faces easily visible marks indicating the name of the factory, the date and quarter year (trimestre) of the manufacture, and the kind of steel, whether Bessemer, Martin, or Siemens; these marks shall be followed by the letter G. These marks shall exactly conform as far as form and dimensions of the letters and figures, thickness, and profile of the relief to the special designs which shall be sent to the contractor by the company. They shall result from an engraving made in the last finishing rolls, with the exception of the special mark indicating the kind of steel, which may be applied after coming from the rolls by a stamp; in the same way the number of the heat shall be punched hot on each rail.

Preliminary Drop Test on an End of a Rail from Each Heat.—Every heat shall give one ingot heavier than the others, in order that in the rolling one rail bar can be obtained which has an excess length of 70 cm, not counting the crushed end. At the saw this crushed end shall be first cut off, and then this excess length of 0.70 m. This part should come from the top of the ingot, and the number of the heat should be marked upon it.

This test piece of 70 cm of length is then placed horizontally upon supports with a span of 50 cm and must withstand without breaking the blow of a 600 kg fall hammer falling freely from a height of 2.50 m for the rails of the type PM–A and PLM–2, and of 3 m for the rail LP and striking at the center. This test is then carried to destruction for informatory purposes.

The two supports shall be of cast iron with rounded angles, and reposing upon an anvil of 10 000 kg of weight, which in turn is fixed in masonry of 1 m depth and of 3.3 m^2 of area at the base.

If any one of the rails fails to meet this test, a rail of the corresponding heat shall be subjected to the final tests described below, namely, those of bending under pressure and impact and the tensile test.

If the rail fails to meet these tests or any one of them, the rails of the whole heat shall be rejected.

When, on the contrary, the preliminary test is met satisfactorily, the rails of the corresponding heat shall be classed with the rails to be subjected to the final tests.

Final Tests of Bending with Pressure and Impact.—The rails shall be divided with care in the mills into heats and in lots of about 300 metric tons at most coming from the rolling of one or several days. The official of tests shall choose in each lot three rails coming from different heats, and from each two samples shall be taken, one of 1.50 m, the other of 3 m in length, which are to be tested, as follows:

First Test.—Each fragment of length 1.50 m resting on the base and supported with a span of 1 m on angular supports must bear the weight on the head during five minutes of 30 000 kg for the rails PM–A and PLM–2 and of 40 000 kg for the rails LP without bending more than 0.5 mm at the center.

Second Test.—The same piece of rail in the same position must, without warping, support the pressure of 45 000 kg for the rails PM–A and PLM–2, and 60 000 kg for the rails LP, without bending more than 20 mm. The test is then carried to destruction.

Third Test.—Each piece of rail of length 3 m is placed upon supports with a span of 1.10 m, and is subjected to the blow of a fall hammer of 600-kg weight falling freely from the height of 1.50 m for the rails PM–A and PLM–2 and 1.75 m for the rails LP, and striking at the center of the span. There shall be no permanent deformation after this test greater than a bending of 12 mm at the center, and the rail must not break. A drop tensile test will not be required for bridge rails. The base and anvil of this machine are described above.

Tensile Tests—Fourth Test.—There shall be made a tensile test on test pieces taken from each of the three rails chosen from each lot. Each test bar cut out cold from the center of the head shall have a test length of 100 mm (between marks) and 13.8 mm diameter. The test bar must support, without breaking, a force of 70 kg per square millimeter, and show after rupture a total elongation of at least 12 per cent of the length between marks. For the rails PLM–2 (special) there shall be chosen heats of hard steel, giving at least 80 kg per square millimeter of ultimate strength (tensile resistance as defined above), but with an elongation which may be of 10 per cent only.

Rejections.—If one of the tests indicated in the above has not been passed, it shall be repeated on three new rails taken from the same lot as the first, and if any one of these latter fail to pass the test the whole lot shall be rejected. But in any case the whole heat shall be rejected of which any specimen has failed to meet any one of the tests prescribed.

Supervision of the Manufacture.—The supervision of the manufacture shall be done at the factory by one or several agents of the company, who shall remain there during the time of the manufacture of the rails, and to these agents the permission shall be given to exercise day and night the surveillance and make the verifications necessary to obtain the assurance that the conditions set for the manufacture as above indicated are being exactly fulfilled. They shall always have access into all of the places where the manufacture is being carried on.

The agents may address their observations to the superintendent or manager of the plant or to his representative, and not to the workmen or foremen (contremaitres).

Provisional Acceptance.—(Omitted.)

Guarantee.—The acceptance at the factory is not final. The rails may be inspected anew at the place of destination. Moreover, all of the rails which in transport, during or before the laying of the same, shall break or deteriorate, for whatever cause it may be, shall be rejected.

The guarantee shall have a duration of six years, counting from the date of the manufacture; in the case that the rails are destined for a line of construction of which the opening shall be delayed, the length of the guarantee period shall not be less than three years from the date of the opening of the line in which the rails are laid.

The guarantee extends to all rails put out of service or deteriorated for any reason other than that of ordinary wear, with the exception of rails altered in an accident, duly noted.

(Articles 23 to 34 are here omitted, dealing with indemnities, final acceptance, delivery, penalties, payment, etc.)

SPECIFICATIONS FOR STRAIGHT STEEL AXLES FOR LOCOMOTIVES AND TENDERS (1906, 1908)*

Where specifications differ from the Paris, Lyon & Mediterranean Railways specifications for axles for carriages or freight cars, they are given below.

Manufacture.—The ingots shall be of basic Martin steel. The company reserves the right to use acid steel if guaranties of the quality of the charges of scrap used in the charges are given.

Testing—Taking of Samples.—The axles are grouped in lots of 25, all of which must be from the same heat.

Drop Test on the Body of Axle.—The first three blows are calculated from the formula $PH = 0.26\ D^2$; the second group of three blows, from the formula $PH = 0.30\ D^2$.

SPECIFICATIONS FOR STEEL AXLES FOR CARRIAGES AND FREIGHT CARS(1905, 1908)*

Identical with those of the Eastern Railways.

SPECIFICATIONS FOR STEEL TIRES FOR LOCOMOTIVES, TENDERS, CARRIAGES, AND CARS (1910)*

Identical with those of the Eastern Railways (MP 21).

SPECIFICATIONS FOR IRON OR STEEL WHEEL CENTERS, WITHOUT RIBS OR SPOKES (1904, 1912)*

Where differing from those of the Eastern Railways (41 MP), specifications are given below.

Tolerances.—In weight for rough wheels, -3 or $+4$ per cent; for rough finished or finished, -3 or $+3$ per cent.

SPECIFICATIONS FOR WHEEL CENTERS, WITH WELDED SPOKES OR RIBS (1904, 1912)*

Where differing from Paris, Lyon & Mediterranean Railways specifications for single plate nonribbed steel wheel centers, specifications are given below.

CLASSIFICATION.—Wheels of iron or of steel (acier soudé), rough, machined, or finished (ébauchés ou finis).

They may be (1) of simple spokes, (2) of double laminated spokes, (3) plates with ribs.

MANUFACTURE.—The welds shall be perfectly made.

2. **Tests—Nature.**—The tests shall include welding, quenching, and bending tests on samples (for steel only).

No analysis for phosphorus is required.

There shall be made on every 50 pieces two tests of weldability, quenching, and bending.

TAKING OF SAMPLES.—These shall be taken from the parts least damaged by the resistance tests on whole wheels. (See Paris, Lyon & Mediterranean Railways specifications for cast-steel wheel centers.)

WELDABILITY (ONLY FOR STEEL-WELDED WHEELS).—The samples shall have a cross section of about 15 to 25 mm by 40 mm and be about 250 mm long.

The specimens are broken and welded together in a lap weld in two heats.

QUENCHING TEST.—The specimen is heated to about 700°C, and quenched in a large volume of water. After cooling it is bent over a mandrel whose radius is equal to the thickness of the specimen.

Similarly the welded piece is bent at the weld until it forms a U with an interior distance equal to the thickness of the specimen. These bends must be made without rupture or cracking.

These tests are carried to destruction in order to examine the grain of the fracture which must be sound.

RESISTANCE TESTS ON WHEELS—(1) *Bending.*—The amount of bend must be for spoked wheels, 1 per cent, and for ribbed wheels, 1.5 per cent. There shall be no evidence of failure at any point of the wheel during this test.

(2) *Expanding Test on Hub Bore.*—The amount of expansion must be 3 per cent.

SPECIFICATIONS FOR CAST STEEL WHEEL CENTERS (1905, 1912)*

Specifications differing from those of the Eastern Railways are given below.

Manufacture.—The material may be of Bessemer, Martin, or crucible steel.

SPECIFICATIONS FOR TENDERS (1912)*

Wheel Centers.—The forcing of centers on to axles is to be done in the presence of an agent of the company. This is done gradually, by means of a hydraulic press, and shall take about five minutes. The end pressures shall be between 40 000 and 120 000 kg.

Shrinking of Tires.—This is done after axle forcing. The tire may not be heated above a dull red for this purpose.

Hammer Test of Tires.—The tires after mounting are struck with a 8-kg hammer while rotating, whereby the sound must be uniform and clear from all parts.

INSTRUCTIONS FOR THE MAINTENANCE OF MOUNTED AXLES, WHEELS, AND TIRES NO. 717 (1908)*

Principles applied in the upkeep of axles, wheels, and tires.

3. Axles are withdrawn from service (1) when fissures or transverse cracks show, (2) because of presence of longitudinal cracks, (3) when the diameters of journals or cranks are reduced by 6 per cent or the length of journal by 10 mm.

(*a*) Wheel centers are withdrawn when (1) two rim fissures appear, (2) one fissure or more in the spokes, (3) reduction in thickness of rim of 5 mm.

(*b*) Wheel centers with cast hub: (1) Two fractures at rim, one in a spoke or a reduction of thickness of the rim of 5 mm, (2) deformation of spokes or fissures in same.

(*c*) Wheel centers without ribs: (1) More than three fissures at the rim, (2) more than two radial fissures form in the plate (bracket).

BELGIUM

STATE RAILWAYS †

SPECIAL SPECIFICATION[15] SHEET NO. 220 (1906)

The following are the laws, regulations, and specifications covering the processes of manufacture and methods of inspecting and testing of rails:

(Paragraphs dealing with contractual details, penalties, etc., are omitted.)

Shape of the Rails.—The rails must present the exact shape of the stamped templet (which has been given to the contractor as a model). The form of the rails must be strictly kept the whole of their length and especially at the ends, where care should be taken to avoid distortion at the time of cutting.

The places where the tie-plates are to be put must be perfectly smooth at the shoulder and at the base. A pattern, which gives the form of the plate, must be attached without delay. The end pieces of the joints (congés de raccord) must have exactly the measurements indicated in the plan.

Length of the Rails.—The normal length of the rails will be 18 m, and at the most one-fifteenth of the tonnage may be ordered in rails of 17.88 m in length.

(A paragraph dealing further with the lengths of rail to be furnished is here omitted.)

The tolerance in regard to the established lengths must not exceed in any case 1.5 mm more or less.

Weight of the Rails.—The normal weight of the rails is 50 kg per meter (in the case of secondary lines) and 57 kg (in the case of trunk lines having a fast running time.)

In the case of partial lots a tolerance of 2 per cent, more or less, will be allowed on this weight, provided that the total amount of the supply is not more than 1 per cent less or more than the normal weight. Within this tolerance and below the rails are to be paid according to their real weight. When the weight is more, the contractor will not be paid for the excess weight.

The rails having weights outside of these limits may be rejected if the inspector deems proper.

For each lot accepted the weight per meter shall be calculated from the weight as determined of at least 50 rails of normal length, taken in different heats, and chosen half by each contracting party.

Marks of the Rails.—The rail must bear on the two faces of the web, but not opposite each other, the distinct mark of the factory or mill of the contractor, the date of the year of the contract, and the letters A B or A T, according to whether the rails are of acid Bessemer or Thomas steel.

These marks must be made by engraving in the hollow or groove of the rolls.

They must be as plain as possible without hindering, however, the putting on of the tie-plates.

The rails must also have a number imprinted hot which will change with the heats and which will be of use in distinguishing the rails coming from the same or from different heats.

The letter T must be imprinted hot after the number of the heat on all the rails coming from the upper part of the ingots of metal.

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[15] These specifications concern the delivery of Vignole steel rails of normal weights of 40.65 kg per meter. However, the weights have since been changed to 50 and 57 kg per meter.

The Finishing.—The rails must be perfectly straight the whole of the length without any leeway. They must be straightened hot on leaving the rolling mill with the greatest care, so as to reduce as much as possible the amount of cold straightening. This must be done without impact and by gradual pressure.

All the rails must be milled at the ends so as to present a perfectly clean section perpendicular to the axis. The milling burrs shall be carefully removed, and no trace of cutting hot shall be visible. (Paragraphs follow dealing with the position of the tie-plate holes, and which are here omitted.)

Ingots, Metal, Tests, Marking.—The ingots must be able to make at least two rails of normal length (18 m).

The discards at the two ends of the ingots must be such that the fractures made near the ends of the rails will not show any traces of cracks or cavities or any other defects.

The rails must be of hard and tough steel. The fracture must show a material of fine grain, compact and homogeneous, free from white points, and coarse crystalline areas.

Tests of Rails.—The administration will receive only the rails which can pass the following tests. (The numerical values of the following tests apply to the rails of the weight 40.65 kg per meter):

1. In the case of each heat the impact test will be made by the commission as described here below on part of a rail about 2 m long having been stamped on the web, when hot, with the number of the heat to which it belongs.

This piece of a rail must be taken from the upper part of the ingot. (*It must not then be cut hot except on one end.*)

Each rail piece resting on the base on two supporting points 1.10 m apart must support the shock of a weight of 500 kg falling from a height of 4 m at the center of the span.

The two supports for this test must be of cast iron resting on an anvil of about 10 000 kg, which is on a foundation of masonry of at least 1 m in thickness and resting on solid earth.

The whole base must not suffer any perceptible deformation under the action of the weight.

If a break in the rail takes place, two whole rails of the same heat and coming from the upper part of two ingots must pass the drop test, but from a height of 6 m instead of 4 m. (The letter T must be stamped when hot on all the rails of this class after the number of the heat.)

If one of these rails does not pass the test, all the rails marked T coming from this heat must be refused, and the drop test must be continued on the other rails of this same heat. If one of these rails is broken, the entire lot from that heat must be refused.

2. The commission will then take from the supply presented from one-half to 1 per cent of the number of rails, each rail taken coming from a different heat.

Half of the rails thus taken must bear the stamp of the letter T. A portion of about 60 cm in length must be cut from each one of these rails to be submitted to the tensile test under the following conditions:

The bars having a diameter of 16 mm in a length of 200 mm between marks, taken from the head of the extremity of the rail (bourrelet) (these test bars may in exceptional cases be taken from the rail discards of the top of the ingot; if the results obtained thus are not satisfactory, the tests shall be continued in conformity with the regulations just given), must have a minimum tensile strength of 70 kg per square millimeter, with an elongation which may not be lower than 10 per cent.

The metal must take a good quench, so as to be cut with difficulty with a file.

3. The other parts of rails in question which can be cut again in 5 m lengths must resist the drop test from 6 m under the conditions described above.

If one of the last two tests is not satisfactory, the tests must be continued on a greater number of rails, and if more than a tenth of all the tests by the tensile test or by the drop test do not give the prescribed result, the entire supply offered for acceptance must be refused.

4. Parts of rails of about 3 m coming from the heats which have given the *greatest* amounts of bending in the first test mentioned above, after being placed on the base on two supporting points 1.10 m apart, must support for five minutes a weight of 25 000 kg at the middle of the two supporting points without being permanently deformed.

5. Rails of the normal length or parts of rails of at least 3 m in length coming from heats which have given the *least* amounts of bending at the first test mentioned above, when placed on their base, must be able to be curved when cold, following a curve of a radius of about 100 m without crack or seam appearing at any point.

The heats which do not satisfy one or the other of these last two tests may be refused.

Besides the tests prescribed above the commission can use any other means of testing that it judges suitable. For example, it may have rails broken in the drop test or otherwise in order to be sure of the good quality of the steel, and of the satisfactory manufacture of the rail.

6. The tests must take place at the mill and at the contractor's expense by means of apparatus furnished by him. The commission may verify the exactness of this apparatus and reserves the right to proceed to tests at the contractor's expense at the place where it judges suitable, in the presence of the contractor, who has been duly summoned for this.

In case of his absence he can not bring any complaint in regard to the applying of the tests. Analyses or other tests at the laboratory at Malines may also be required. In this case the expense of transportation of the objects to be tested from the factory to the place designated in the bids as the place of shipment, shall be borne by the contractor. The contractor shall furnish without charge boxes and other objects necessary for the shipping of the test pieces to the agents of the commission, and also ends of rails to be sent for test. It is not permitted to the contractor to re-present for acceptance rails which have already been subjected to test.

The rails which have been received must be marked at the two ends.

Repairing.—It is expressly forbidden to hammer, heat, or file rails with the purpose of concealing the defects of manufacture. The rails which present traces of such fraud must be thrown away.

SPECIFICATIONS TYPE XX (1906)†

The laws, regulations, and specifications now (1912) in force in Belgium covering the process of manufacture and methods of inspecting and testing of wheels and axles for freight and passenger cars and locomotives were adopted November 8, 1906, and are as follows:

General Regulations Common to Purchase of Wheels and Axles and All Other Articles.—All articles presented for delivery must conform exactly to the models or to the indications of the plans which have been submitted. They must be made according to all the rules of that industry; they must be without defect and their completion must not leave anything to be desired. They may not be covered with any greasy material.

In order to avoid any damage in the course of transportation in the loading or the unloading, the parts of the axles must be preserved from all contact by covering them with solidly fastened planks or boards.

It is expressly forbidden to hammer, heat, file, or engrave parts which are to be furnished in order to conceal the defects of their manufacture. Every piece which contains anything of this kind will be refused.

Where it is possible, every article must have the mark of the person to whom the contract of supplying it was awarded and also that of the manufacturer, and if it is deemed necessary, the date of the approval of the contract or the number of the specification, according to the case as well as the final date of the time limit of the guaranty.

When the quality of the material to be used is not stated in special terms or by plans, materials of the best quality must be chosen.

Independent of the tests specified in the specifications or in the contracts, the commission appointed for the receiving of the goods can submit the articles to such tests as they may deem fit.

When a test has resulted unfavorably, the commission (Commission de Réception) may authorize a second test on the request of the contractor.

If the commission finds that 10 per cent of the articles presented do not satisfy the conditions agreed upon, they can refuse all of that contract of supplies. The manufacture of the axles, bodies of wheels, cranks, mainsprings (pivots), and of the mounted wheels can be made only in establishments approved by the Government.

SPECIAL REGULATIONS

Crank Axles for Locomotives, Locomotive Tenders, and Cars.—These axles must be of iron or steel at the choice of the contractor. The metal used must be of extra quality.

The axles must be completely finished; the bearing parts must be perfectly polished; the others must be painted white.

The bearing necks must be perfectly cylindrical and the greatest attention must be paid to see that they do not acquire in turning the least tapering in length; the hollows of the elbows must be made entirely and exclusively by a slotting machine.

In the case of models of axles whose cranks (pallettes) are shrunk on (frettées) the collars must be of No. 4 iron or of iron of the same kind which can be welded. The collars must be finished according to the indications of the plan in order to obtain perfect contact with the axle crank. No trace of calking will be tolerated.

The dimensions indicated in the plans must be rigorously observed.

Marks must be arranged as follows, placed in letters of a centimeter in height at the position marked C in the sketch (here omitted):

Name of contractor:	Nature of metal:
Number of specification:	Name of manufacturer:
Final date of guaranty:	

Straight Axles of Locomotives, Axles of Tenders, Passenger and Freight Cars.—The straight axles must be of steel of the very best quality. The kind of steel and the manner of manufacture are left to the choice of the contractor.

MARKS.—The marks to be applied must be stamped when hot. Each axle must present at the place given in the plans an oval or rectangular cavity 4.5 cm long, 1.5 cm wide, and 0.5 cm deep, which is to receive the marks of the temporary accepting, of the accepting, or of the refusal.

CONDITIONS OF MANUFACTURE.—The axles must be entirely finished according to the indications of the plans which have been given; the journals must be turned so that the center points of the extremities can be maintained. The axles of passenger cars must be entirely turned. The journal must be perfectly polished and cylindrical and have no scratches, cracks, etc.

TESTS.—The axles must be presented in series of 50. If the quantity to be furnished is equal to or less than 50, they must be presented in one delivery. For each series or fraction thereof a supplementary axle must be furnished which is to take the

place of the one designated for the impact test. This condition must be likewise fulfilled for the series of less than 50 axles which make up the balance of a contract. If the supply includes axles of different models, the contractor must add an extra axle for each of the models presented. No tests will be made until these conditions have been fulfilled.

The axles must undergo tests after their completion. They can, however, be presented and tested in the unfinished state on condition of being submitted again for the examination of the commission after completion. The transportation charges both ways, entailed in making use of this privilege, are to be supported by the contractor.

The axles can also be tested when in the rough condition as to the quality of the material and the manner of manufacture to be used in the shops of the manufacturer on condition that these shops are located in Belgium, but the examination of the parts as to defects and dimensions must always be made at the place where they are to be supplied.

The tests must be carried on as follows:

The commission for acceptance will commence by refusing axles bearing exterior defects such as cavities, defects in the welding, both longitudinal and transverse. The axles must be then grouped in series of 50. The commission must choose from each series an axle which, when placed on two supports 1.500 m apart, must withstand a blow of a hammer of a weight P falling from a height H determined by the following formula:

$$PH=0.00318\ d^3$$

P being the weight in kilograms, H the height in meters from which it falls, and d the diameter in millimeters of the middle of the axle.

If the axle breaks or shows cracks, the series to which it belongs must be refused.

If the contractor is not opposed to it, or if he expresses the desire, the commission can have the impact test made on the axles refused for defects other than failure to satisfy the physical requirements.

When the undertaking comprises the furnishing of axles of different models, the supplementary axles, for which a test will not have been deemed necessary, if they are free from exterior defects, must be delivered at the prices of the contract, in the case of axles furnished as exchange pieces delivered at a price to be determined according to the results of the former contracts, and if it has to do with axles entering into the composition of sets of wheels with axle attached.

Tires for Locomotive, Tender, Carriage, and Car Wheels.—The tires shall be of steel (of which the carbon content shall not be less than 0.30).[16]

DIMENSIONS.—The profile given shall be rigorously adhered to. A caliper shall be applied to the tire without delay; the shoulders and fillets shall have exactly the dimensions indicated in the drawings. The special specifications or order for the tires will indicate the profile and interior and exterior diameters desired in the tires.

MARKING.—The marks shall be put on hot at the place indicated. The tires shall bear the heat number, which is of a series beginning each year. Before the marking each tire must present on the said surface three rectangular cavities.

MANUFACTURE.—The tires shall be made of ingots, which have been forged under the hammer on all the faces, and not of billets (rondelles) which have only been rolled.

The rolling shall be as perfect as possible; the surface shall be smooth and free of surface defects, such as seams, fissures, etc., clean and smooth, and free from fins, cavities, lines, or other faults of any sort. The tires shall be perfectly plane without the least warping. The administration reserves the right to have the melting of the

[16] This specification omitted in 1912.

steel and the process of manufacture inspected by one of their agents, for which purpose they shall be advised two days in advance of the day and the hour of each melting or heat and of the time when the ingots will be put into the mill. The ingots shall be carefully grouped by heats, and shall bear, readily visible, the number of the heat from which they come. The manufacturer shall keep a memorandum of the production in ingots of each heat, of the weight of the ingots, of the result of the tests practiced at the plant, and of the number of the tires which he will have obtained. These memoranda shall be communicated to the engineer agents of the administration when they shall demand them; and the manufacturer shall carefully examine all ingots before proceeding further, and those having flaws, such as blowholes (soufflures), fissures, etc., or those coming from a heat adjudged defective shall be rejected.

The ingots shall be charged to the reheating furnaces cold, and care shall be taken that they may there be disposed in such a way that it may be immediately seen from which heat they come. All of the ingots from the same heat shall, when possible, be rolled together. Precautions must be taken in the course of the manufacture of the tires that the ingots, blooms, or tires coming from different heats may not become confused.

Testing of the Finished Product.—The commission will proceed to examine the surface of the tires, and should there be cause for the rejection, those showing scratches, cavities, cracks, transverse or longitudinal, shall be rejected. From among those sound in the above respect the official of tests shall choose one tire from each heat for test.

Drop test.—These tires shall be subjected to a drop test in which the weight of hammer and height of fall are determined by the following formulæ:

$PH=Kbe^2$.

P=weight of hammer.

H=height of fall.

b=width of tire.

e=thickness of tire at running surface.

K=constant for various profiles.

K=0.01257 for tires for locomotives and tenders, profile No. 1, method of attachment of the London-Chatham-Dover Co.

K=0.01106 for tires for locomotives and tenders, profile No. 2, method of attachment of the Alsatian Society.

K=0.01146 for tires for locomotives and tenders, profile No. 3, method of attachment of the Caledonian Railway.

K=0.01286 for tires for passenger and freight cars.

Nevertheless, it is permitted for the tires provided with the Caledonian method of attachment to use the following specifications instead of the above ones for the impact test.

"1. The tire must allow of a reduction under the press of one-sixth of the original diameter measured on the tread surface without fracturing or fissuring.

"2. The material must have an ultimate strength in tension of at least 71 kg per square millimeter, with an elongation of at least 17 per cent measured over a length of 0.508.

"The tires tested in the impact test shall be struck three blows, and at the end of the second one the reduction of vertical diameter shall not be greater than one-seventh of the original for tires of wheels for locomotives, tenders, freight and passenger cars. After the third blow the tire shall not fracture or show signs of fissuring. Otherwise the tires of that heat are to be rejected."

Conditions Common to all Tires.—The contractor is obliged to replace all tires tested in accordance with the contract covering the furnishing of tires in exchange. The administration reserves the right to submit each tire, after it has been mounted on the wheel, to tests with the hammer, made by hand or with special apparatus. The tires which do not pass these tests shall be rejected, and the tires returned to the contractor, who must replace them if the hammer test has been made in the course of the tentative or final acceptance of the wheel sets or pairs. If it is a question of replaced tires, the tires which shall not have passed this test shall be considered as having been placed out of service by the application of the conditions of the guaranty.

TOLERANCES—OVALIZATION.—An ovalization, or a difference between two interior diameters whatever, of the tires is not allowed except on the condition that the greatest interior diameter and the minimum exterior diameter remain within the tolerances indicated below. In any case the ovalization in the case of tires for wheels for freight cars is limited to 2 mm at the most.

EXTERIOR AND INTERION DIAMETERS.—There is allowed a tolerance of -2 mm in the interior diameter and of ± 2 mm in the exterior diameter. No tolerances are allowed in the other sense in either diameter.

WIDTH.—There is allowed a tolerance of ± 1 mm in the width of the tires.

(There follow further paragraphs dealing with the tolerances which are here omitted.)

Conditions Common to Straight Axles and to Tires.—When the drop test has resulted unfavorably, if the commission for receiving decides that there is reason for two tests, the second test will be on two axles or upon two tires. If this new test is favorable, the supply may be accepted.

In order to render account of the quality of the material used, the commission for receiving can break the axles and the tires which have been refused because of defects or because of tests, and the contractor can not claim any indemnity for this.

If the quality of the material is found to be bad, the lot may be refused even when the results of the impact test have given satisfactory results.

The axles and tires refused for the different reasons will be returned to the contractors after the placing of a mark of refusal by the commission for receiving, which will have the privilege of causing them to be shown at any time up to complete finishing of the contract.

The axles and tires upon which the tests have been made, being in every case considered as refused, will be charged to the account of the contractor.

Bodies or Centers of Wheels for Locomotives and Tenders.—The bodies of the wheels must be of wrought iron (fer forgé) or cast steel. When cast steel is used the words "acier coulé" (cast steel) must be marked in the casting on the outside face of the body of the wheel in letters 2 cm high and 2 mm in relief.

Bodies of Wheels in Wrought Iron.—The welding of the spokes of the hubs and of the outer rim of the wheels must be of perfect workmanship. The bodies of the wheels must come from the forge in good condition.

Bodies (Corps) of Wheels of Wrought Iron and Cast Steel.—The bodies of the wheels of this kind must be without defect: the spokes must be straight. The outer rims must be turned, and there must not be any spot which has not been touched by the turning tool. The hub must be turned on its vertical surfaces and its bore reamed in such a way as to be perfectly adapted to the wheel seat (portée de calage). The counterbalances must be cast or welded on and not be merely attached to it. The wheels with elliptical spokes are admitted on the same footing as wheels having rectangular spokes.

The physical properties of the steel wheel centers are as follows: Tensile strength, 40 kg per square millimeter; elongation for 200 mm test length, 15 per cent. The bodies of the wheels must be marked on the hub.

Bodies or Centers of Wheels for Passenger and Freight Cars.—The bodies of wheels for passenger and freight cars must be one of the types which figure in the plans which have been given.

No leeway will be allowed in regard to the diameter of the rim of the wheels nor in regard to the interior diameter of the hub.

The body of the wheels must be of wrought iron or steel. In case cast steel is used the metal must have a tensile strength of 40 kg per square millimeter, with a minimum percentage of elongation of 10 per cent, the tests being made on bars 200 mm long.

The marks and the gauge measurements must be made under the care of the contractor, but under the inspection and according to the indications of the delegates of the commission of delivery.

Sets and Pairs of Wheels.—The special conditions imposed upon the elements forming parts of the sets and pairs of wheels have already been given above.

(Beginning below, with the paragraph headed "Placing of the wheels upon their axles," the text is not complete, as the original contains much matter which is irrelevant to the present purpose.)

Placing of the Wheels Upon Their Axles—General Conditions.—The tires must be put on hot and must fit perfectly. The fastening must be obtained by a decrease of the inside diameter of the tire in connection with the outside diameter of the outer rim of the wheel.

This decrease must be 1 mm per meter of the exterior diameter of the outer rim of the wheel.

The wheels must be placed quite symmetrical to the axis of the axle journal. The two tires of the same pair of wheels must have the same exterior diameter. The fastening of the tires on the wheels must be done with the greatest care.

The contracting parties must produce an official report showing the pressure in kilograms with which each wheel has been put on the axle. This report must be drawn up so that later, at the time of furnishing, the pressure at which each one of the wheels has been put on can be easily verified. This report in regard to the pressure does not prevent the commission for receiving from proceeding to tests.

Wheels of Locomotives and Tenders.—The cranks can be put on the axle by pressure hot or cold, at the choice of the constructor. This operation must be done with the most minute care under the guaranty of the constructor.

The cranks of the same pair of wheels must be placed exactly square the one as regards the other.

The application of the wheels on the axles must be made by hydraulic press under a pressure of at least 80 000 kg. However, this pressure of application is 60 000 kg for wheels of locomotive tenders, type 11; 70 000 kg for axles of bogies of locomotives, types 15, 17, and 18; 85 000 kg for axle motors and couplings of locomotives, types 15, 17, 18, 30, and 32.

Wheels of Passenger Cars and Freight Cars.—The wheels must be applied on the axles with heavy friction.

The pressure of application must be at least 40 000 kg for the sets of wheels with axle journals of 225 by 130; it must be at least 35 000 kg for sets of wheels with axle journals 170 by 97, 205 by 110, and 242 by 120; it must be at least 30 000 kg for sets of wheels with axle journals 150 by 80.

The application pressure must be at least 80 000 kg for sets of wheels with axle journals 180 by 130 of braked vans, baggage cars with chassis in cast iron. The commission for receiving cars, if it judges suitable, may have a certain number of the wheels of the supply to be furnished demounted. The supply will be refused if the pressure required for putting the wheels on again at the test does not come up to 80 000 kg, 40 000 kg, or 30 000 kg, according to each category.

Pairs of Balanced Wheels for Passenger Cars.—Besides the conditions which have preceded, the pairs of balanced wheels must fulfill the following conditions:

WHEEL CENTERS.—The centers of the wheels must be carefully turned according to the indications of the plans which have been given. The interior surface of the hub of the wheels and the outside surface of the rim must be strictly concentric; any eccentricity is not allowed. After finishing the wheel centers must be weighed and the indication of the weight of each one of them must be imprinted on the outside face of the hub. The balancing weight (balourd) must then be verified by means of an axis perfectly centered engaging the hub and resting on two horizontal supports. Every wheel center whose balancing weight measured at the rim shall exceed 0.5 kg will be refused.

Each center will receive then on the inner surface of the rim the indication of the value of the balancing weight at the exact spot where it has been ascertained. The observing of these regulations must be established prior to putting on the axle by a mark of temporary receiving.

The Mounting of the Centers of the Wheels.—The axles must be completely turned. The tires must be turned on every side to the dimensions indicated in the plan which has been given.

The centers of the wheels must be mounted on the axle so that their respective balancing weights (balourds) are in the same plane passing through the axis and on the same side of this axis so that they join each other.

The sum of these balancing weights (balourds) must not exceed 0.750 kg. The center of gravity of the whole system must coincide with its central axis; that is to say, the set of wheels being suspended by the middle of the axle, the axis of this latter must rest in equilibrium in a horizontal position.

The position of equilibrium can, however, be established at the time of receiving by means of a weight suspended in the middle of the axle journal. This weight can not exceed 1 kg. The conditions of equilibrium imposed upon the pairs of wheels unprovided with tires must be fulfilled the same as when the sets of wheels are furnished with their tires.

The following are considered as being unfit for service: Parts which break, tires which are only 30 mm thick at the center of the section, tires which become loose in service, and, finally, any part which is in such a state which will endanger the security of service.

The guarantees are as follows:

	Years.
Wheel centers for passenger and freight cars	2
Axles for passenger and freight cars	3
Tires for passenger and freight cars	3
Crank axles	3½
Wheel centers for locomotives and tenders	4
Straight axles for locomotives and tenders	4
Tires for locomotives and tenders	5

SPECIFICATIONS (SPECIAL) NO. 1439 (1913) †

Modifications in Regulations and Conditions Regarding Crank Axles for Locomotives.—The special conditions in the specifications, Type XX, approved November 8, 1906, were modified and completed as follows:

The crank axles for locomotives must be of nickel steel; this steel must have a minimum tensile strength of 60 kg per square millimeter.

The minimum elongation percentage must be 18 per cent on a length between points 200 mm apart and the minimum reduction of area (striction), 45 per cent, the diameter of the specimen being 20 mm. The specimens must be taken in the pro-

longation of the crank axles and in a longitudinal sense. Placing a mark at the extremity of each axle will be sufficient for this.

The reduction of area must be understood here as being the proportional reduction of a section of the test piece. It is expressed in millimeters by the formula:

$$\frac{A-a}{A} \times 100$$

in which A represents the original section and a represents the section of fracture.

Among the marks this steel must be marked by the letter N to distinguish the nickel steel from the ordinary steel.

GUARANTIES.—The furnishing of sets of wheels or pairs of wheels of straight and crank axles, of centers of wheels, etc., subject to guaranties as to length of time of service.

The contractor is notified when the guaranty commences, either when the contract has been approved or at the time of the order.

The commission for receiving condemns parts found to be defective during the time of the guaranty.

SPECIAL SPECIFICATIONS FOR LOCOMOTIVES (1907)*

Cast Steel.—Cast steel shall have an ultimate strength in tension of at least 40 k per square millimeter with an elongation of at least 15 per cent on a length of 200 mm. When the elongation can not be measured on a greater length than 100 mm it shall be at least 18 per cent. All pieces of cast steel shall be perfectly annealed.

Axles and Straight Axles.—For each series or fraction of a series of 50 axles there shall be furnished an extra axle for test purposes. (Identical with specification, Type XX.)

Wheel Bodies and Centers.—(Identical with Type XX of specifications.)

Crank Axles.—(Identical with Type XX of specifications.)

Guarantees.—Wheels and their constituent parts are guaranteed for the following periods:

	Years.
Straight axles	4
Crank axles	3½
Wheel centers	4
Tires (furnished to the contractor by the administration)	2
Tires (furnished by the contractor)	5

GERMANY

COMBINED PRUSSIAN AND HESSIAN STATE RAILWAY ADMINISTRATION

SPECIAL REGULATIONS FOR THE DELIVERY OF RAILS AND TONGUE RAILS (1912)

1. Kind and Properties of the Material.—(1) The rails shall be manufactured of soft steel (Flussstahl); the method of manufacture is left to the manufacturer; it must, however, be given in the bids.

(2) The material of the finished rails must be tested according to the special regulations for the testing and acceptance of materials and those of paragraph 6 for strength and toughness. The criterion of the strength shall be tensile and compression tests, of toughness, the drop test.

(3) The ultimate strength in tension must be at least 60 kg per square millimeter of original cross section. In the compression test the penetration of a ball of 19 mm diameter shall be not more than 5.5 mm and not less than 3.5 mm, with a pressure of 50 000 kg. In the drop test the rails must stand the following test:

A span of 1 m of a rail with the head lying up shall be able to bend at least 100 mm at the center under the blows of a hammer tup at the center of the span without breaking or showing flaw of any kind. The tongue rails must, under the same conditions, bend 130 mm.

2. Manufacture and Quality.—(1) The rails must be rolled out accurately according to the drawings and the templet made from them. The templets must be stamped with the stamp of the railway administration, in order to show that they have been compared with the original templet at the administration's central office in Berlin, if they do not already bear the stamp of the earlier Cologne railway administration at Essen. The contractor may buy the necessary templets from the railway administration, and is, however, obliged to have the correctness of the same tested by the railway administration testing agent before the rolling is done. In acceptance of rails only templets which have been compared with the original one may be used.

(2) Variations in the height and head width of 0.5 mm are allowed, in the base width, of 1 mm.

(3) The rails may not be heated after being rolled. A little cold straightening is permitted; this must, however, be done carefully in the straightening press with nonimpact pressure, and neither the supports or the stamp may leave marks on the rails in the process.

(4) The finished rails must not be warped nor show flaws, such as fissures or seams.

(5) Hammering or welding up fissures and similar attempts to cover up flaws are particularly forbidden. The chiseling off of fins, etc., is only allowed when they are not greater than 1 mm and are not located at the ends of the rail or the upper, rounded edges of the head.

(6) The machining of the ends is only to be done with circular saw or milling machine. The surfaces must be perpendicular to the longitudinal axis of the rail. In the case of rails with scarfed joints the depth of the cut must be accurately adhered to.

(7) The rails must be provided with the holes shown in the sketch, which are to be bored. The close-up rails shall be characterized as such by holes of 20 mm diameter in the web at one end.

(8) The burr caused by the machining is to be carefully removed.

3. Length of the Rails.—(1) The rails are to be furnished according to demand in the lengths given in the drawing and which are as follows: (A long table dealing with the actual lengths is given here, which is not reproduced. The lengths vary from 12 to 18 meters.)

(3) The contractor is obliged to furnish upon demand a certain fraction of the total weight of the rails in shorter lengths, which fraction is to be definitely settled in the contract. The contractor is, however, entitled to demand that the delivery of the shorter rails be made as far as possible at the same time as that of the rails of normal length.

(4) On the other hand, the contractor may require that in the case of rail types 6, 7, 8, 9, 15, and 16, at least 6 per cent of the total weight shall be ordered in lengths which are at least 0.5 m less than normal. He is, on demand, obliged to furnish the half of this 6 per cent in the case of the rail types 6, 7, 8, and 9, in lengths of 10 m or other proper length, constant for the whole half, while the shorter lengths of the rail types 15 and 16 are to be all 12 m.

(5) In the case of tongue rails the furnishing of lengths shorter than those specified by the administration is not permitted.

(6) Rails up to 9 m in length are allowed a tolerance in length of ± 2 mm, those over 9 m a tolerance of ± 3 mm.

4. Weights of Rails.—(1) (The weights of types of rails are given; here omitted.)

(2) The following method is used for the determination of the weight of rails for which payment shall be made:

(*a*) The weight of the finished and accepted rails is determined by weighing at the plant of the contractor, and under the direction of the inspector, 5 per cent of the whole lot for delivery. The average weight found in this manner shall be taken as a basis for the price calculation.

(*b*) The weights should be as follows: (A table is given of the weights, which are theoretical; here omitted.)

(*c*) A tolerance of ± 3 per cent and -2 per cent is allowed in the weight, and overweight will be paid for up to 1 per cent; in all other cases the actual weight will be paid for.

5. Marking.—(1) Every rail must bear the manufacturer's mark and the year of intended installation on the web.

(2) The marks are to be made in accordance with the sketch.

(3) Rails of lengths other than those given in article 3 are to be marked with white paint on the two ends. The lengths of these rails are also to be painted on the web at the tie-plate holes, in white.

6. Testing.—(1) In order to determine to what degree the finished rails satisfy the conditions of paragraph (1), lengths of rail 1.3 m long shall be chosen in which there are no track bolt holes or notches, and drop tests shall be carried out on these. In these tests equal blows of 1500 kgm impact work shall be applied until the rail piece has been bent the amount required in section 1.

The last blow can be made with an energy suited to the bending to be accomplished. The temperature of the test piece is to be determined and noted. In the case of about one-third of the test pieces the test is to be carried to destruction; if necessary, the rupture is to be brought about by notching. Unusual phenomena in the mode of deformation of the test piece and of the mode of fracture are to be investigated as far as possible and noted.

(2) Tensile and compression tests shall then be carried out with the test pieces from the impact test; for the tensile test, test pieces, of the form and shape shown in the drawing (this sketch was not included in the specification and can not be here reproduced, but attention is called to the general form of tensile test pieces shown on p. —) shall be taken from the center of the head of the least bent part (cut out

cold) and tested in the tensile machine. Besides the ultimate strength, the elongation and the reduction of area shall be determined.

(3) The official making the tests is empowered to choose from each 200 finished rails, or in case of delivery of a smaller number, from each smaller lot, one rail, which is to be subjected to the above-mentioned tests. One half of such rails are to be tested in tension and the other half in compression.

(4) If the test rail fulfills only in part or not at all the specifications given above, a second, and even a third, rail shall be chosen from the same heat and tested. Each of these rails is to be subjected to the tensile and to the compression test. If either one of these last rails fails to meet the requirements of the test, the heat will not be accepted. For the purpose of these tests all rails must bear on the web the number of the heat.

(5) If in the further tests of these rails the impression is gained that the material is faulty, and if in their inspection flaws or other evidences of inferiority are found, the lot may be rejected. In these cases the appropriate clauses in the contract apply in the consideration of delays or damage which may ensue as a result of such rejection.

(6) Those rails accepted by the official of tests are provided with the acceptance stamp and are suitable for delivery. Unstamped rails may not be accepted unless the testing and the acceptance take place at the same place.

7. Guarantee.—(1) The guarantee provided in the general contract clauses for the furnishing or contracting begins with the acceptance and ends after a period of five years, reckoning from the end of the year of intended installation or laying of the rails as indicated by the date rolled on the rail.

(2) In the case of tongue rails the guarantee extends only to the replacement for those rails, which in the course of working or machining are shown not to be according to specification, because of unsound material or because of faulty manufacture. The guarantee period ends on December 31 of the year following that of the final acceptance of the rails.

(3) The fulfillment of guarantee on rails, which fail during the guarantee period, is made by cash settlement on the basis of the table of weights of article 4. The replaceable rails shall be ceded to the railway administration at a scrap price of M 65 per (metric) ton, as long as the number of such from any one plant in any one railway division (Bahnmeisterei) is not greater than three in one year.

(4) The application for the fulfillment of the guarantee is made through that division of the administration, in which the failed or defective rails are found, whereas the payment is settled through that division in which the contract was made.

SPECIAL REGULATIONS FOR THE DELIVERY OF PARTICULARLY HARD RAILS (BESONDERS VERSCHLEISSFEST) (1912)

These are the same as for other rails with the exception of the following clauses:

(3) The ultimate strength in tension shall be at least 70 kg per square millimeter. In the hardness tests the penetration of a ball of 19 mm radius shall be not greater than 5 mm and not less than 3 mm, with a pressure of 50 000 kg.

In the impact test a span of 1 m of the rail lying with the head up must stand the blows of a hammer tup in bending 80 mm at the center before the failure occurs.

7. Guarantee.—(1) The period of guarantee (defined in the same way as for ordinary rails) is seven years. The guarantee extends also to rails which, before the end of the seven-year period, show in the middle part of the rail more than 4 mm wear in the height, or at the ends, an amount of wear, which is more than 1 mm greater than that in the middle of the rail, and further to rails in the case of which, because of too great wear of the rail ends, the tie-bolts do not fulfill their function. When the necessity for recovery on these latter rails occurs before the end of a period of five years, only the price increase (contractual) for the longer guarantee period and for the greater tensile strength is to be paid. If this necessity occur only after the

end of five years and before the end of seven years only the price increase for the longer guarantee period is to be paid.

PRUSSIAN STATE RAILWAYS ADMINISTRATION

REGULATIONS FOR THE QUALITY AND TESTING OF MATERIALS FOR ROLLING STOCK (1908)†

Quality—General.—The materials for rolling stock, in regard to their quality and mode of manufacture, shall correspond to the following conditions: The least values of the tensile strength are to be understood as those loads in kilograms per square millimeter of the original cross section, which the test piece will bear; the least value of the elongation, as that fractional part of the original test length, as prescribed below (and in the drawings), by which the test length is increased after fracture. The test length shall be 200 mm whenever possible, and not otherwise prescribed. The specifications for tensile strength and elongation hold no matter whether the material has been formed by forging, pressing, rolling, or casting.

3. STEEL (FLUSSSTAHL).—The steel must be tough and of homogeneous structure.

(*b*) The tensile strength of steel, acid or basic, Martin, Thomas, or Bessemer, for axles and tires shall be at least 50 kg per square millimeter; for locomotives and tender tires (Martin steel), at least 60 kg per square millimeter. As a test of the toughness a drop test shall serve (see below). The tires must be shrunk on to the body of the wheel with a shrinkage of 1 mm for every meter of inner diameter, without tearing or showing any flaw which could be ascribed to the material or the process of manufacture.

(*e*) *Crucible Steel for Tires.*—This material must have a tensile strength of at least 70 kg per square millimeter. A drop test shall also be carried out.

(*g*) *Nickel Steel for Axles.*—The material for locomotive crank axles must have a nickel content of 5 per cent and that for axles up to 120 mm in diameter, one of 2 to 3 per cent. The tensile strength shall be at least 60 kg per square millimeter and the elongation 18 per cent, the reduction of area at least 45 per cent.

4. CAST STEEL.—The cast steel must be tough, dense, and quite homogeneous in structure.

The cast piece shall be clean, full at the edges and corners, and may contain neither fissures nor pipe. The coupons and risers must be carefully removed. Sharp-cornered shoulders are to be avoided.

The tensile strength must be at least 50 kg per square millimeter and not more than 60 kg per square millimeter, with an elongation of at least 16 per cent, which may be taken over a test length of 100 mm.

5. SOFT STEEL (FLUSSEISEN).—The tensile strength may not be more than 50 kg per square millimeter. The steel must possess a homogeneous structure, must have taken cleanly the desired form, rolled out full-edged; it may have no flaws, such as cracks, seams, or holes.

(*c*) *Soft Steel for Wheel Plates.*—The tensile strength may be between 40 and 50 kg per square millimeter. A drop test shall be the criterion of its toughness.

6. CAST SOFT STEEL (FLUSSEISENGUSS).—The cast steel shall be tough and of homogeneous structure throughout. The casting shall be clean and full at the edges and corners and may contain neither fissures nor pipe. The coupons and risers shall be carefully removed. Sharp-cornered shoulders are to be avoided. The tensile test shall serve as a criterion of the strength and the elongation; the drop test, in the case of certain cast forms (wheel centers), as a measure of the toughness. The elongation may be measured on the original length of 100 mm. The annealing of the test pieces is not permitted unless the casting is also to be annealed. Over a test length of 100 mm the tensile strength shall lie between 37 and 44 kg per square millimeter with an elongation of at least 20 per cent.

7. WROUGHT IRON.—This must be of fibrous structure, dense, easily forgeable and weldable, neither hot nor cold short, and must be free of flaws, slag, blowholes, seams, etc.

Tests.—1. GENERAL.—The materials are, as a rule, to be tested before use in the plant of the contractor or subcontractor. If the testing of the materials is done at the request of the contractor, not in his own, but in the plant of his subcontrator, he must pay to the Government the costs caused thereby, such as wages of the inspector and traveling expenses, etc.

The parts which are according to specification are, as a rule, stamped with the test stamp, which should be made easily visible by marking over or near it with white paint.

The material to be tested must be treated in just the same way as all of the material for that lot which is represented. After the selecting and marking of specimens for test these may not be afterwards annealed. (For exception in the case of wheel tires, see par. 2 under 4.) Therefore the test pieces chosen by the inspector are to be cut out cold and cold machined. Every test specimen must be distinctly stamped and numbered and be taken from parts or articles which have the same dimensions and have been manufactured and treated in the same way as the others of the same lot. (Some paragraphs relating to sheet metal and wood are omitted.) The railway administration reserves the right to have tests carried out on material in its own shops or in those of any plant which is near, besides those carried out in the shop of the contractor. If there is in the plant of the contractor or furnisher no apparatus for the testing of materials, the testing of the materials must be done at the cost of the contractor in a railway shop. For such tests the articles or parts to be tested and the test pieces for the tensile test, the latter in duplicate, must be sent prepaid to the indicated railway shop. These test pieces must be machined and in the form suitable for test; if not, they will be machined in the railway shop at the expense of the contractor.

From those test articles and pieces tested at the shops of the contractor sample and fractured pieces must, at demand, be sent prepaid to the administration. The contractor is, however, not obliged to preserve these longer than three weeks. No damages will be paid for articles which have been rendered useless in the course of testing.

2. EXTENT OF THE TESTS.—The official of tests is empowered to choose one of every 50 (or part thereof) locomotive, tender, or freight-car axles, wheel tires, or other parts of rolling stock for purposes of testing.

In the case of crucible steel tires, one of every 25 (or part thereof) may be tested; if the test piece chosen fails in the test, the whole lot or part thereof shall be rejected, unless in the judgment of the inspector some local and unimportant fault was responsible for the failure of the tire chosen, in which case two others will be chosen, and if either of these do not fulfill the specifications, the lot must be rejected.

The soft steel cast wheel centers are all to be provided with test coupons, out of which tensile test pieces may be taken. The inspector may take from every 10 wheel centers one tensile specimen, and, further, from every 50 wheel centers, or part thereof, one may be taken for the drop test. From the parts of the latter test specimens may be taken for the study of the homogeneity of the metal.

Those axles, or tires, which are from the same heat must be kept separate until the tests are concluded, and the contractor is obliged at any time to state which of them belong to any one heat.

The tests of axles and tires are not to be begun until the list of the heat numbers has been given to the inspector.

If test pieces fail to meet the tests, then the pieces from that heat must all be rejected.

If the official of tests gets the impression that failure to meet the tests is due to insignificant local flaws, two further test pieces may be chosen from the same heat for test, which must both meet the requirements.

Before taking the second and third specimens, the whole lot of the respective heat may be annealed. If only one of these fail to meet the tests, the articles from that heat must be rejected.

In case small variations are found from the required conditions, and the inspector believes that an error of measurement may explain these, it is permitted to make not more and not less than two further tests to ascertain whether the material is fit for acceptance or not.

If in further tests the inspector is not convinced of the faultless quality of the material, or other defects or faults appear during the inspection or acceptance which indicate the defective quality of the material, the railway administration may reject the whole lot. For damages which arise from this reason or because of delay in the furnishing of the articles to be inspected the regulations of paragraphs 7, 10, and 12 of the general contract regulations hold.

3. DROP TESTS.—(*a*) *Construction of the Drop-Testing Machine.*—The machine must have such a height that an impact work of 5600 kgm is possible.

The base must be of masonry, of which the size is limited by the building conditions but which must be at least 1 m deep.

The supports for the test piece must be fastened, wedged, for example, to a cast-iron base of one piece resting on the masonry construction and which weighs at least 10 000 kg.

The tup guides shall be of metal, for example, rails, and shall be so constructed that no great side play is possible. It is recommended that the guides be lubricated with graphite. The center of inertia of the tup must lie in the center line of the guides and the ratio of the guide length of the tup to the inside width of the tup must be greater than 2 to 1. The form of the tup is to be chosen such that the center of inertia lies as low as possible. The mass of the hammer may be of cast iron, cast or forged steel; it is to be fastened with a coupling device to the tup holder symmetrically to its center of inertia; the fulfillment of this condition shall be made recognizable by special marks. The striking face shall be rounded with a radius of not less than 150 mm, and the striking line shall be perpendicular to the center line of the hammer. The weight of the tup shall be 1000 kg, but if this is not possible, it shall be as near as possible to 500 kg. The clutching device shall be of such form that it does not hinder the free fall of the tup and will prevent the accidental falling of the same.

A device must also be installed to prevent the complete fall of the hammer in case it is accidentally released, and which will protect persons engaged at the machine from injury.

The graduation of the upright guides in meters and decimeters must be possible of vertical displacement and easily visible to the observer.

In the case of drop tests with wheel tires the tup shall strike upon a piece of at the most 20 kg in weight, which is plane above and corresponds below to the profile of the tire. The tires shall be supported in the correct position for taking the blow.

The supports for the axles shall be half cylindrical, saddlelike form of half radius of 50 mm. Devices must be used to prevent the flying out of axles or tires when struck; such devices must not affect the deformation caused by the blow.

The contractor is obliged to furnish a sketch of the machine used to test his materials at the demand of the railway authorities, and to give the inspector an opportunity to test its correctness.

(*b*) *Drop Tests With Axles.*—The axles to be tested may be either rough or machined; in the test they are to be supported on supports with a span of 150 cm, and struck in the center of the span. Locomotive axles must withstand eight blows of 5600 kgm and tender axles the same number, of 4200 kgm impact work. After each blow they are to be turned over.

Car axles of 145 mm wheel-seat diameter shall, with blows of 3000 kgm each, bend 180 mm at the center without any signs of failure, while those of 130 mm diameter must bend in the same way at least 200 mm. In the tests with the car axles they are not to be turned, but the blows are to be applied in the same direction.

After each blow the amount of bending is to be measured, and the fall height of the tup regulated according to the bending, which has taken place. The last blow may be regulated in intensity according to the amount of bending to be accomplished.

The bending of the axles is to be measured at the upper surface of the axle and is to be computed in terms of the original span.

A semicircular rod device, with perpendicularly attached movable measuring strip at the center, with millimeter scale is to be used in measuring the bending of the axles.

The temperature of the axle is to be determined during the test and noted.

(*c*) *Drop Test With Wheel Tires.*—The tires, placed perpendicularly under the hammer, must be able to bend under the blows of the tup, which fall on the center of the tread, in the manner described in the following without showing any signs of failure. The impact work of blow shall be 3000 kgm and shall be increased each time by 500 kgm if the flattening is less in amount than 10 mm for each blow. After each blow the diminution of the perpendicular inside diameter is to be determined with calipers and the fall height of the tup regulated according to the amount of bending which has taken place. The last blow of the hammer may be taken of an intensity to correspond to the amount of bending to be accomplished. The temperature is to be noted.

Tender and Car Tires of Martin, Thomas, or Bessemer Steel.—The flattening of these tires shall be at least 12 per cent of the original inside diameter.

Locomotive Tires of Martin or Crucible Steel.—The flattening in this case may be calculated from the formula

$$E = \frac{D}{100} - \frac{d-65}{10}$$

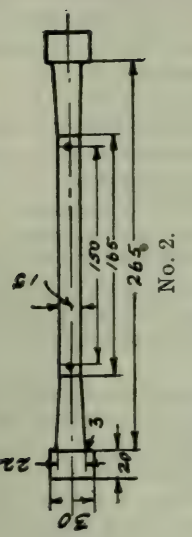
In this formula E is the flattening in per cent, D the tread circle diameter, and d the average tire thickness in the tread circle in millimeters.

(*d*) *Drop Tests With Wheel Centers.*—The wheel centers are to be laid with the rim on wooden supports in a horizontal position. A mandrel, consisting of four segment pieces, whose inside width is diminished by 1 mm in 20 mm is placed in the hub bore. A steel cylindrical wedge of square cross section, fitting exactly into the segment mandrel, is then forced under the drop hammer into this mandrel. For wheel centers with a hub bore of 145 mm this shall be done with six blows, for those of 130 mm bore, with five blows of 300, 400, 500, 600, 700, and 800 mkg, respectively. The mandrel and wedge are to be rubbed with oil before the test and wiped off. After this test the wheel centers must show neither in the hub, spokes, nor in the rim cracks or damage of any sort.

The test may, in the case of about one-third of the test wheel centers, be continued to destruction; if necessary failure is to be brought about by notching.

Uncommon phenomena in the deformation of the test pieces and in the type of fracture are to be investigated as fully as possible and noted.

Tensile and Elongation Tests.—The round test specimens shall have diameters of 10, 15, 20, and 25 mm, and shall correspond as much as possible to the dimensions of the sketches below. (See Nos. 1, 2, 3, and 4.) When possible, however, the diameter of 20 mm should be chosen. When round test specimens without heads are to be tested, and held in wedges, the length between the ends of the latter shall be as nearly as possible equal to the length between the shoulders of the normal test specimens of the same diameter.



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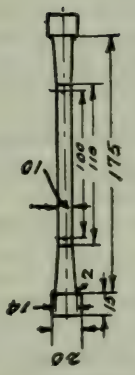

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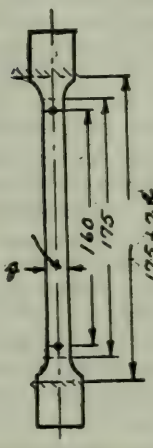

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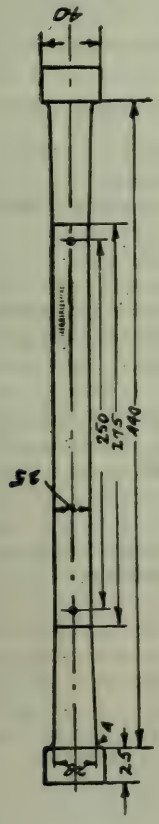
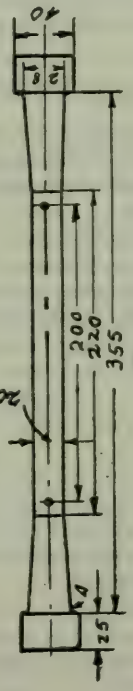


No. 1.,



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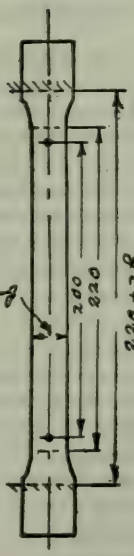


No. 5.

The flat specimens shall correspond in dimensions as much as possible to the drawings Nos. 5 and 6. Over the test length the cross section shall be at least 200 and when possible 300 mm^2, with a width of from 20 to 40 mm. The test length in the case of specimens of from 200 to 300 mm^2 in cross sectional area shall be 160 mm, that in the case of those of greater cross section, 200 mm.

In the case of axles, the test specimens are to be taken from the portions least bent in the impact test; in the case of tires, from the center of a cross section, which has been bent the least, and from a piece, which has been straightened as little as possible. The least bent portions are generally to be found at an angle of 40° to the vertical.

The round test specimens for axles, tires, and wheel centers shall have diameters of 20 mm, the flat test specimens, cross sectional areas of at least 300 mm^2, and both shall correspond as far as possible to the sketches 3 and 5. Only for the test specimens of cast steel and of cast soft steel may the elongation be measured over a test length of 100 mm.

When a test specimen, because of definitely recognizable fault of machining or local material flaw, or of faulty method of holding in the testing machine, gives an unsatisfactory result, the results are not to be considered as a criterion of the quality of the material with respect to tensile strength and elongation.

When the fracture occurs outside of the center third of the test length, the result for the tensile strength still holds, but not that for the elongation if the latter do not reach the prescribed amount. For the correct determination of the latter a new test specimen must be tested, in which fracture must occur in this center third of the test length.

CONSTRUCTION AND TRAFFIC RULES, GERMAN STATUTES, 1904*

Wheels.—29. WHEEL PRESSURE.—The wheel pressure of trains not in motion may not in general be greater when loaded to full capacity than 7000 kg.

On track over which the superstructure and bridges are sufficiently heavy the pressure may be as great as 8000 kg.

31. WHEELS.—(1) The wheels must be fastened securely on the axles.

(3) The tread circle must be at least 850 mm in diameter.

(4) The wheels must have flanges, except in the case that there are three or more wheels on the same frame, in which case the middle wheels need not have flanges.

(5) MEASUREMENTS OF WHEELS:

	Mm
(*a*) Width of tires:	
Minimum	130
Maximum	150
(*b*) Thickness of tire, minimum	25
(*c*) Height of flange over tread:	
Minimum	25
Maximum	36
(*d*) Thickness of flange, measured 10 mm beyond the tread, minimum	20
(*e*) Play of wheels on the rails (side):	
Minimum	10
Maximum	25

Axles.—The greatest allowable stresses by static loading shall be:

	Kg/cm^2
(*a*) For axles of steel (Flusstahl):	
For freight cars—	
In journal	700
In the wheel seat	560
For passenger, baggage, and mail cars, and tenders—	
In the journal	560
In the wheel seat	450

(*b*) For axles of wrought iron:

For freight cars—	
In the journal	590
In the wheel seat	470
For passenger, baggage, and mail cars, and tenders—	
In the journal	470
In the wheel seat	380

GERMAN RAILWAY CAR ASSOCIATION

SPECIAL REGULATIONS CONCERNING THE CONSTRUCTION AND FURNISHING OF FREIGHT CAR WHEEL SETS (1910)

Materials.—(1) The regulations furnished as a supplement are authoritative for the quality and testing of materials.

(2) Axles and tires are to be made of steel (Flusstahl), spring rings of soft steel (Flusseisen), the body of the wheel (wheel center and plate center) of soft steel, wrought iron, or cast soft steel.

(3) The method of manufacture of the steel is, in so far as it is not prescribed, left to the manufacturer; it must, however, be stated in the bid.

Construction.—(1) The axles must be forged from sound, homogeneous ingots under the hammer or press. It is allowable to roll the ingots or forged axles in order to give a smooth surface. If the axles are each forged from separate ingots, the average cross section must be at least four times as great as that of the rough forged axle; if, on the other hand, the axles are forged out of bloomed ingots, the average cross section of the ingot must be at least eight times as great as that of the rough forged axle.

(2) The axles must be turned down smooth over the whole surface; sharp shoulder edges are not allowed.

(3) The wheel seat must run without any shoulder (Ansatz) on the inner side of the wheel hub. The journals must be finished in the cylindrical part and in the throat ground and polished accurately to dimensions; work with the file is not allowed.

(4) The centers on the heads of the journals are to be made before the turning down of the axles. They may not be afterwards bored out.

(5) The wheel centers according to sketch must be welded together in the seat spokes, and rim to one piece and thoroughly cleaned. The wheel centers, according to sketch C9, are to be made by forging and rolling out of one piece (Ehrhardt's process), the wheel centers according to the same sketch (right), as one piece from soft cast steel (Krupp process). The spokes must be straight. Holes or other surface defects may not occur on any part of the wheel centers.

(6) The method of manufacture of the wheel plates must be given in the bids. Cast wheel plates are not accepted.

(7) The weight which may be placed in the periphery of a wheel, in order to bring the center of gravity in the axis of the seat bore, may not be more than 0.5 kg.

(8) The rim of the wheel body must be machined on the tire-supporting surfaces and on the faces, and must possess a uniform thickness.

(9) The hubs of the wheel body must be machined on both faces. The bore of the hub and the wheel seat must have a smooth surface; the boring of the hub must be made from the inside and the machining of the body of the axle from the journal.

(10) The tires must be manufactured from sound and homogeneous ingots by means of the hammer, the press, or by rolling. After rolling, they must be protected from too quick cooling. The inner surfaces of the tires and the grooves for the spring rings are to be machined, and sharp edges are to be avoided.

(11) The spring rings must be long enough that the two ends of the ring after insertion be not more than 1 mm apart.

Assembling.—(1) The two wheel bodies pressed on to any one axle must be of the same construction. The wheel centers must be so placed on the axles that the spokes of the wheels coincide when looking in the direction of the axle. In the case of plate wheels the holes for the grippers must also so coincide.

(2) The difference in weight between the two wheels of the same set may not be greater than 2 kg. The extra weights on the periphery of the wheels of the same set shall be as nearly equal as possible and shall both be in the same plane containing the axis of the axle and on opposite sides.

(3) The wheel bodies shall be pressed onto the axles in such a way that the pressure be transmitted through a sleeve inclosing the journal onto the inner collar of the journal. The pressure shall begin at the latest after a distance of 20 mm and shall increase until the wheel is in position. The final pressure shall be between 60 000 and 90 000 kg.

(4) The wheel presses are to be provided with pressure gauges, which give a diagram of the course of the pressing of the wheel on the axle. The scale of this diagram shall be such that 100 atmospheres of pressure give 40 mm, and that the rate of unrolling of the record strip is at least 20 mm per minute.

(5) The tires are to be shrunk on with a shrinkage of 1 mm per meter inside diameter.

(6) The tires are joined to the wheel bodies by means of spring rings. The tires must be carefully dressed (angerichtet) over the whole periphery after the setting in of the spring rings, but must not show any tool marks after such treatment.

(7) The running and side faces are not to be machined until the tires are fastened on the wheel bodies. Both wheels must have accurately the same tread diameter (Laufkreisdurchmesser). The tread planes must be at the same distance from the center of the journals. The finished wheel sets must be accurately round.

Flaws of Manufacture.—It is not permitted to cover up flaws in the materials, such as welding joints, blowholes, etc., by cementing (welding) or calking.

Marking.—(1) The finished wheel sets shall be stamped in the following way on both ends of the axle (drawings are shown indicating the positions of the various marks, which are here omitted):

In letters 8 mm high, name of the firm furnishing the material for the axles with the number of the heat (year, heat, and ingot number), as well as the name of the material, and name of the firm providing the wheel set, with day and year of the delivery of the finished set.

In letters 15 mm high, shortened characterization of the type of wheel set (pair) and year in which the type originated, the two together giving the type of wheel; name of the owner; and wheel pair number.

(2) The tires are to be provided according to sketch on the outer ring surface 15 mm from the inner edge with the manufacturer's number, the mark of the contractor, the year of the delivery, the year and piece number, as well as the shortened characterization of the material. The abbreviated characterization of the material must be made according to the regulation above. In the case of tires which are submitted in the unfinished condition for delivery or sampling, a round impression of 2 mm diameter must be made for the acceptance stamp back of the mark characterizing the material. The digits of the heat number and the piece number must be 8 mm high; those of the other numbers, as well as the acceptance, must be about 5 mm deep, or at least must be so hammered in that they remain easily visible after the machining.

(3) The wheel bodies shall have on the outer surface of the hub in letters and figures 3 mm deep the mark of the delivering firm, the year of delivery, and the name of the owner in letters 15 mm high. The pressures in kilograms used in pressing the wheels on the axle shall be marked in letters 15 mm high, the weights and the

excess weights of the wheel bodies in kilograms in letters 8 mm high, the forcing pressure and wheel weight at a distance of about 10 cm from each other on the side toward the center of the axle, the balancing weight in the direction of its position on the side of the wheel toward the journal.

(4) The exact position of the balancing weight is to be indicated on both side surfaces and the inner surface of the wheel flange by a mark in white paint.

Supervision of the Manufacture and Inspection.—The regulations of the individual association administrations hold for the supervision of the manufacture and inspection of the wheel sets.

Painting and Packing.—The axle journals must be coated with a water-tight and acid-free paint, wrapped in oiled oakum, supported with wooden strips lying on the oiled wrapping, and held together with band iron, or at least in an equally efficient manner protected from damage. The other parts of the wheel set, with the exception of the tread circles of the wheel tires, are to be painted with colorless linseed oil varnish.

The wheel pair must be carefully packed and protected against any motion in order that they may not damage each other.

Guarantee.—The guarantee begins with the day of the final acceptance of the finished wheel set and lasts during a period of three years, and extends to all damage to the sets which occurs because of faults or flaws in the materials or mode of manufacture. The guarantee will be claimed by the owner of the wheel sets in accordance with the latter's regulations in regard to this matter.

ASSOCIATION OF GERMAN RAILWAY ADMINISTRATIONS*

TECHNICAL AGREEMENTS (VEREINBARUNGEN) CONCERNING THE CONSTRUCTION AND TRAFFIC ARRANGEMENTS FOR THE MAIN AND SPUR RAILWAYS (1909)[17]

A. Construction and Upkeep of Track.—(4) The rails shall be in general 9 m long. Greater lengths are recommended, up to 20 m.

(5) FORM OF THE RAILS.—The rail head shall be at least 57 mm wide, the running surface, straight or curved, with a radius of at least 200 mm. *New lots of rails must have a running edge curved with a radius of 14 mm.*

In the case of crosstie track with wide base rails a height of rail of 125 mm and width of base of at least 100 mm are recommended.

(6) CARRYING CAPACITY OF THE RAILS.—*The rails of lines carrying locomotives must be able to support at the greatest velocity wheel pressures which measure 7000 kg statically measured, and from the 1st of January, 1920, at the latest, on pressures of 7500 kg.*

In case of new track construction or of strengthening old track, provision must be made for wheel pressures of 8000 kg.

(7) It is recommended to give rails an inward slope of 1:20.

B. Construction and Upkeep of Rolling Stock.—(64) *The wheel pressure of rolling stock which is likely to be used on other railroads may not exceed in general 7000 kg.*

(65) WHEELS.—*The wheels on braked axles must be provided with shrunk-on tires, the wheel centers or plates of such wheels must be made of wrought iron, steel, or soft steel.* The use of cast iron for the hubs or for whole wheel plates is, in exceptional cases, allowed. *Steel-plate wheels, in which the hub plate and tire are cast in one piece, may only be used for unbraked axles. Chilled cast-iron wheels may be used only for freight cars (unbraked) in which the velocity does not exceed 50 km per hour.*

(66) The diameter of tender and car wheels shall at the tread circle be at least 840 mm. The tread circle is that circle made by the intersection of a plane perpendicular to the axle and at a distance of 750 mm from the center of it with the running surface of the tire or wheel.

(68) *The width of the tires may not be less than 130 mm and not greater than 150 mm.*

[17] Specifications in italics are obligatory, and those in ordinary type are only recommended.

Such tire-fastening devices are to be used that broken tires can not become loosened or come off in pieces from the wheel.

Sharp edges are to be avoided in tires.

The smallest allowable thickness of tires measured in the tread circle is set for all rolling stock at 25 mm. At the last machine cut the thickness shall not be reduced below 30 mm.

It is recommended to leave a shoulder on the outside faces of the tires in order that the thickness of the tires can be measured in the way mentioned above.

Wheel tires whose cross section is weakened by a groove under the throat of the flange must have a thickness of at least 20 mm.

The running surfaces of the wheels must slope outward from the flange toward the center.

(69) FLANGES.—*The wheels must be provided with flanges, except in the case of middle wheels of a frame.*

The height of the flange may not be less than 25 mm nor greater than 36 mm above the tread circle. When the flanges of a pair of wheels are unequally worn, the thickness of the most worn flange must be at least 20 mm at a distance of 10 mm above the tread circle.

(70) SIDE PLAY OF THE FLANGES.—*On a track of width 1435 mm the side play of the wheels must be more than 10 mm and less than 25 mm.*

(72) CAR AND TENDER AXLES.—*Freight car axles of steel must be heavy enough in the journal and in the wheel seat that under the heaviest static load the bending stress in the former is not greater than 700 kg, nor that in the latter greater than 560 kg per square centimeter.*

For axles of wrought iron the stresses shall not be greater than 590 kg in the journal and 470 kg in the wheel seat.

The axles of passenger, baggage, and mail cars and tenders shall not be stressed more than 560 kg and 450 kg when of steel, and not more than 470 kg and 380 kg when of wrought iron in the journal or wheel seat, respectively. Car and tender axles may not have sharp shoulders at or in the wheel seat, and they are to be avoided in general.

PRUSSIAN-HESSIAN STATE RAILWAY ADMINISTRATIONS*

SPECIAL REGULATIONS FOR THE SUPPLYING OF LOCOMOTIVES AND TENDERS (1913)

6. WHEEL PAIRS.—This is the same as special specifications for wheel pairs for freight cars of the State Railway Car Union 1910 with the exception of the following paragraphs:

(6) The wheel bodies of locomotives shall be made of soft cast steel, those of tenders of the same of wrought iron or of soft steel.

Rolled wheel bodies may be furnished for the tenders of freight locomotives.

(7) The position of the center of gravity of the wheels must be determined, and a greater weight than 0.5 kg may not be used at the periphery of the wheel to correct any eccentricity.

(10) The edges of the hub bore shall be rounded.

(16) Only wheels of the same kind may be pressed on the same axles, and the difference of weight between them may not be more than 2 kg.

AUSTRIA

STATE RAILWAYS

SPECIAL SPECIFICATIONS FOR RAILWAY RAILS (VIGNOLE AND CHAIR RAILS) (1909)

(Articles 1 and 2, dealing with the amount of the contract and the bond to be given, are here omitted.)

3. Kind and Properties of the Material.—The rails shall be made of steel.

The contractor must state in the bids what method of manufacture he will use, and this method will be stated in the contract.

The material of the finished rails must satisfy, in respect to its toughness and strength, the specifications of article 5.

The fracture must be fine and uniform and must not show fissures or blowholes.

4. Manufacture and Quality.—(1) The rails must be rolled exactly according to the normal drawings furnished with the contract and signed by the contractor, and according to the official templet furnished the contractor by the state railway authorities and provided with the official seal, which in turn corresponds to the normal drawing.

(2) The rails must be perfectly straight, may not be warped or contain cracks, seams, or other flaws. Such flaws must not be covered up by hammering or cementing (welding). After rolling the rails may not be again heated.

(3) The rails must show in every cross section the normal profile, and variations in the form of the tie-plate seat and in the height of the latter with respect to the running surface are not allowed; differences in the height and width of head of ± 0.5 mm and of the width of base of ± 1 mm are allowed.

(4) The ends must be perfectly even and smooth and perpendicular to the rail axis, with the tie-plate holes bored according to diagram.

(5) The lengths in which the rails are to be delivered will be indicated to the contractor after drawing up the contract; tolerance of ± 2 mm will be allowed in the length of rail of 9 m and below, of ± 3 mm in all lengths over this.

(6) The length predominating in the contract or order is to be looked upon as the normal length.

(7) In order to make the manufacture easier, rails which have come from the rolls in a damaged condition at the ends may be shortened by cutting off these ends.

(8) The number of these shortened rails allowed will be determined by the state railway officials; in cutting down the rails, lengths must be adhered to, which will be made known to the contractor.

(9) All rails of abnormal length are to be marked according to special direction with oil paint on the web.

(10) The rails, after having been finished in the mills, must be protected from nonuniform and too rapid cooling.

(11) Such a process must be used that the rails after cooling may be as straight as possible. A small amount of cold straightening may be done in the cold straightening press by means of repeated and moderate application of the load, which at each application corrects only a small part of the curvature, and which may be applied only to the web in the case of side curvature. No marks should be left on the rail by this process.

(12) The rails may be cut to length only with the circular saw or the milling machine. Tie-plate holes must be bored and notches may not be punched or chiseled out.

(13) The burrs from boring or milling must be removed.

(14) Each rail must have on it the trade-mark of the firm, the year of the delivery, and the characterization of the kind of steel used. These marks shall be on one side of the rail on the web in raised letters. Each rail must also have on it the heat number, with the exception of those shortened rails made from normal rails.

(15) All rails which in one or another characteristic do not correspond to these requirements or show that improper repair work has been done shall be rejected.

(16) The date of the beginning of the rolling of the rails ordered is to be announced in writing eight days before.

5. Tests of Quality.—(1) The rails shall be tested in the factory by the official of tests aided by the contractor.

(2) To the inspector shall be given a list of the heats to be used in the production of rails, together with the number of rails to be obtained from each.

(3) The testing and acceptance will always be done upon notice from the contractor, as soon as all rails, when less than 1000 are ordered, or when more are ordered, at least 1000 rails are ready for test.

(4) The rails when finished shall be divided into groups of about 200 pieces, and one rail from each of these groups shall be chosen for the purpose of the test. A group of rails remaining, and greater in number than 100, as well as single lots of rails over 100 and under 200, are to be considered as a full group, whereas remainders of less than 100, or single lots of less than 100 rails, are not to be considered in the testing.

From each of the rails to be tested shall be cut with the saw two pieces about 1.3 m long, one piece about 0.45 m long, and, in addition, in the case of rails which weigh more than 30 kg to the meter, one piece about 0.15 m long. These are, respectively, for the transverse bending test, the impact test, the tensile test, and the last for the ball-hardness test carried out for the purpose of obtaining information. It is permitted the inspector, however, to take these pieces, during the rolling, from the still red-hot rolled bars—but without hindering the work of rolling—with the saw.

(5) Rails of one heat are to be put in the same group.

(6) If the rail chosen fails to meet the requirements, a second and third may be taken from the same heat and tested in the same way. If either of these latter rails fails to meet the test, the whole heat may be rejected. The other rails of this group shall be considered as a new group and resubjected to test in the usual way.

(7) If the cases in which rails in consequence of faulty material must be rejected repeatedly occur, the state railway administration is justified in obtaining those rails, which have not yet been offered for acceptance elsewhere at the expense of the contractor.

(8) The tests are to be carried out in the following manner:

THE TRANSVERSE BENDING TEST.—(9) This test is made by supporting a piece of the rail about 1.3 m long on supports 1 m apart and loading it at the center for five minutes with a nonimpact load, and using if possible an automatic recording device to obtain the stress-strain diagram, whereby after removal of the load no permanent deformation shall have been suffered.

(10) The load in kilograms shall be calculated from the formula

$$P = 120 \frac{J}{e}$$

where J is the moment of inertia in centimeters^4 of the section with respect to the center of inertia, and e is the distance of the center of inertia from the most heavily stressed fiber in centimeters. This load must act on the head of the rail and only be gradually reached. The test is to be repeated and the load increased to a value from 25 to 30 per cent higher than that at which the material yields. The deformation is to be measured and referred to a fiber length of 1 m.

THE IMPACT TEST.—(11) The piece of rail to be tested is placed upon supports 1 m apart with the head up and in such a position that striking face of the tup of weight of 500 kg shall strike the rail at the center of the span and at right angles to the axis of the rail.

(12) The fall hammer shall be so constructed that the line of the center of inertia of the hammer coincides with the center line of the perpendicular guides and that these guides do not hinder the free fall of the hammer.

(13) The striking face of the hammer tup shall be rounded with a radius of at least 150 mm.

(14) The supports must be fastened to an iron base of at least 10 000 kg weight embedded in masonry, and arrangement is to be made to prevent the tipping over of the rails, as well as the springing out of the rails under the blow, without interfering, however, with their free position.

(15) The tests must be carried out at a temperature of from 5° to 30° C.

(16) The test specimen must withstand one blow of impact work

$$A = 100 \frac{J}{e^2}$$

in kilogram-meters, and further blows of 0.4 of this value until a bending at the center of 100 mm for rails of height up to 129 mm and of 90 mm for rails of greater height has been reached, without fissuring or showing other signs of failure.

(17) The last blow may be regulated according to the bending to be accomplished.

(18) The bending is to be measured on the running surface of the rail and calculated to a fiber length of 1 m.

(19) With one-third of the test pieces the test is to be carried to destruction and the amount of bending is to be measured; if necessary, fracture shall be brought about by notching.

(20) Unusual phenomena in the mode of deformation of the test piece are to be investigated and noted.

THE TENSILE TEST.—(21) The tensile-test specimens may be cut out of the rails cold, only, and no such piece of rail or test specimen shall be subjected to any heat or other treatment before test, except that necessary to the taking of the specimen.

(22) A test specimen shall be cut from the head of the rail and shall have the form shown in the sketch (test length 24 cm and diameter 25 mm).

(23) The tensile strength must be at least 65 kg per square millimeter. Further, the elongation over 200 mm and the reduction of area must be determined.

(24) *The Ball-Hardness Test.*—For this test, which is carried out only in the case of rails with a weight of more than 30 kg per meter for the purpose of obtaining information, the 150 mm rail piece is used, and the penetration and diameter of depression of a steel ball of diameter 19 mm at a pressure of 50 000 kg and 10 000 kg, respectively, are to be determined.

(25) *The Chemical Analyses.*—The official of tests is to have access to the results of the chemical analyses made during the manufacture of the rails, and in particular to those of the heats of which test specimens are submitted for the mechanical tests. He is also entitled to take smaller test pieces (pieces of rail, etc.) from the plant for his own information.

6. Tentative Acceptance.—(1) The results of all of the tests carried out are to be drawn up in manuscript, and this is to be signed by the inspector of the State Railway Administration and the contractor or his agent.

(2) Each group of rails in the case of which the tests have been satisfactory must still be inspected, piece by piece, by the inspector in respect to its outer appearance, such as for form, position, and diameter of the bolt holes, for the length, etc., and then the determination of the real weight will be made.

(3) The inspector (for acceptance) of the State Railway Administration decides alone the question of the acceptability of the rails.

(4) The rails which are found to fulfill the specifications will be marked on both ends with a stamp and are then tentatively accepted.

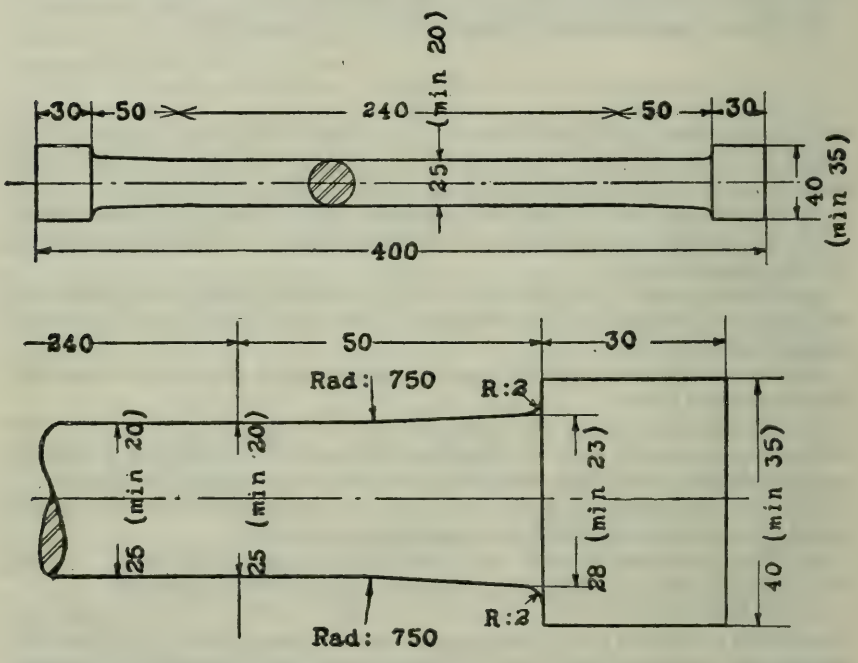
(5) In corroboration of this, the contractor receives from the inspector of the State Railway Administration a statement concerning the accepted and stamped rails, which gives their number, length, and weight.

(6) The stamped rails, if not immediately shipped, must be stored regularly in piles and protected as much as possible from rusting.

(7) Rejected rails are to be so marked by means of a crossed acceptance stamp.

(8) The contractor must see to it that of the whole order the proportion of number of rails of the different lengths, even in the part lots for delivery, shall be adhered to.

7. Normal Weight.—(1) The normal weight of any definite type of rail is that



weight which can be calculated for a length of 1 m on the basis of the known normal area of cross section and a specific gravity of the rail steel of 7.85 kg per cubic decimeter.

(2) For the determination of the actual weight, a determination, by means of a carefully tested scale or balance, shall be made under the direction of the inspector of the weight of 5 per cent of each accepted lot, and the weight of the whole lot calculated from this result.

(3) Excess weight is allowed up to 3 per cent; underweight, up to to 2 per cent of normal weight.

(4) The actual weight will be paid for, with the reservation that overweight over 1 per cent will not be paid for.

8. (This article deals with the shipping of the rails and is here omitted.)

9. Final Acceptance.—(1) The final acceptance takes place at the place of destination after verification of the stamp of the inspector at the rolling mill, verification of the marking of rails of abnormal length, and further, after investigation of the superficial appearance of the rails and determination of the number of the same.

(2) Unstamped, as well as stamped, but damaged or bent, rails will be rejected, which are to be replaced by rails of the same sort without flaws at his own cost by the contractor and removed.

(Further clauses follow, of no technical importance, relating to a possible further weighing of the rails.)

10. Guarantee and Claim for Replacement.—(1) The guarantee imposed upon the contractor (see the General Regulations Concerning the Bidding on and Furnishing of Material and Equipment, edition 1902) for the specified quality of the Vignole and chair rails begins with the acceptance and ends after five years, which in the case of rails which are intended for laying in old track is counted from July 1 of the year marked on the rail. In the case of rails intended for laying in new track the guarantee period is counted from a date three months before the day of the opening of the new line or division.

(2) Rails which are damaged after final acceptance in consequence of carelessness in transporting, or through accidents out of the ordinary, such as derailments, cave-ins, etc, or because of being run over by locomotives or ballast trains before the completion of the proper substructure, are to be replaced by the contractor only in case flaws or defects in the material or method of manufacture are discovered.

(3) On the other hand, the contractor must replace all rails during the guarantee period which in the course of ordinary service of any kind are damaged in consequence of defects in the material or arising in the mode in which the rails have been manufactured—as, for instance, broken rail, flowed head, or deformed rail—within two months after the claim has been sent to him by the State Railway Administration by repayment of the cost of the rails.

(Articles 11, 12, and 13 deal with the payment, penalties, etc., which are here omitted.)

SPECIFICATIONS FOR AXLES FOR LOCOMOTIVES, TENDERS, AND FREIGHT CARS (1909)

1. Material, Manufacture, and Quality.—The material for axles may be only basic Martin steel, or a steel known to the buyer to be the equal of this material; it must be tough and homogeneous and of equal hardness throughout; the method of manufacture is subject to the acceptance and approval of the party ordering the axles.

Two qualities are distinguished—basic Martin steel, mark A, of from 55 to 65 kg per square millimeter tensile strength and at least 16 per cent elongation; basic Martin steel, mark B, of from 45 to 55 kg per square millimeter tensile strength and at least 17 per cent elongation.

The phosphorus content may not be greater than 0.05 per cent. The axles shall be made by forging or pressing down ingots. Each axle is to be forged into a length longer than the finished axle is to be, and this extra length is such that it can be removed by chisel or hammer. The finished (forged) axles shall be suitably annealed and cooled out of contact with the air. The axles must be free from blowholes, pipes, fissures, and other flaws.

2. Dimensions and Weight.—The axles are to be furnished according to order as forged, rough machined, or machine finished. The dimensions indicated in the sketches included in the order or contract for the axle in either of the conditions mentioned are to be adhered to, and in no case may the dimensions be less than these. The weight given on the sketch may not be exceeded by more than 5 per cent for the forged or 3 per cent for the rough machined axles, and further overweight will not be paid for.

(Article 3 deals with the marking of the axles and is here omitted.)

The inspector must be furnished with a list of all axles which are to be submitted, which, arranged according to the order, contains the numbers of the heat or of the ingot of each axle. After acceptance the acceptance stamp of the railway administration is to be framed with a line of white paint in order that it may be easily visible.

4. Testing of the axles.—The "Regulations for the Testing of Materials for Rolling Stock" form a supplement to the following specifications:

(*a*) DROP TESTS WITH LOCOMOTIVE, TENDER, AND FREIGHT-CAR AXLES.—With respect to the testing of axles for locomotives, from the first lot of each heat one axle shall be chosen for the drop test. If the rest of the steel of this heat is used for the production of further lots of axles for the same order, then on one axle of each lot an extra length of 400 mm will be left from which a tensile specimen can be cut.

In the case of axles for tenders and freight-car wheels one axle from each heat will be chosen.

The axle to be tested is placed with the wheel seats on two rounded supports, which are fastened to the base of the drop-testing machine. The distance between these two supports shall be 1.5 m. This axle shall be subjected to blows of 3000 kgm impact work until the bending measured on any 1.5 m long fiber is equal to that calculated from the following formula:

$$E=\frac{1350}{DF}$$

where E is the bending in millimeters, D the diameter in meters of the axle at the center, and F the maximum tensile strength for the material type in question. The impact work of the last blow is to be so chosen that the bending prescribed is not much exceeded. Then the axle is turned through 180° and straightened out in the same way. The axle must not develop fissures or fracture during this deformation. The axle is then to be tested to destruction in order to judge of the structure, and for this purpose may be notched. The fracture must be uniform and fine and may contain no pipes or blowholes.

In order to carry out the foregoing test with locomotive axles it is permitted to machine the axle to the uniform diameter of the middle part.

(*b*) THE TENSILE TEST.—From each axle tested under the fall hammer two tensile test specimens shall be cut out cold of the wheel seat part, except in the case of locomotive axles. In the inspection and acceptance of locomotive axles, the heat of which has already been subjected to the drop test, the control tensile test specimens shall be taken from the extra length.

If one of the tensile specimens gives results under the required values, the average value of the two tests may be taken.

(*c*) FAILURE TO MEET THE TEST.—If of any one heat the first axle fails to meet the impact test, two more axles shall be chosen and subjected to the same test. If either one of these latter axles fails to meet the requirements of the specifications, the heat must be rejected.

If the results of the tensile test on an axle which has met the drop test are not satisfactory, the repetition of both tests with another axle of the same heat is allowed. The failure of either one of these tests allows of the rejection of the whole heat.

(*d*) The railway administration reserves the right to make other tests, such as chemical and etching tests, to assure itself of the quality of the material. The phosphorus content may not be greater than 0.05 per cent and heats whose chemical anaylsis is not satisfactory may be rejected.

SPECIFICATIONS FOR TIRES FOR LOCOMOTIVES, TENDERS, AND FREIGHT CARS (1910)

1. Material, Manufacture, and Quality.—Tires must be made of basic Martin steel or of material known to the consumer as of equal quality, and it must be of the best quality tough, homogeneous, and without flaws and of the proper hardness. The mode of manufacture is subject to the approval of the party ordering the tires. The phosphorus content must not be above 0.05 per cent.

There will be distinguished between the following qualities:

(*a*) Basic Martin steel, mark 1, of more than 75 kg per square millimeter tensile strength. The railway administration reserves the right to order such material with properties to be especially agreed upon.

(*b*) The same, mark 2, of 65–75 kg per square millimeter for locomotive and tender tires.

(*c*) The same, mark 3, with 55–65 kg per square millimeter for freight-car tires.

For the last two materials the sum of the numbers for the ultimate in tension and five times the elongation in per cent must be at least 130.

(A table of the ultimate strengths and the corresponding elongations is given, which is not here reproduced.)

Before their further manufacture, porous or other inhomogeneous parts of the tire ingots must be removed.

The rolled and finished tires are to be suitably annealed and left to cool out of contact with the air.

The finished tires may not contain fissures, pipe, splinters, slag (Schiefer), or other porous or defective spots. The tires must be rolled out smooth, equally heavy, accurately round, and not warped, and such that the increase of 1.5 mm in the diameter is sufficient to allow of shrinking on of the tire, and that with this increase the finished and correct profile and cross section of the tire may be attained in all sections.

2. Dimensions and Weight.—The tires are to be manufactured according to the indications given in the order, and must fully correspond to the dimensions of the sketch. In particular the tires may not possess a greater inner diameter than that prescribed; a smaller diameter by at the most 1.5 mm is allowed. The inner cylindrical surface of the tire must be accurately perpendicular to the plane side flange surface.

The weights of the different tires are given in the corresponding sketches. Excess weight of more than 5 per cent will not be paid for.

(Article 3 deals with the marking of the tires, and is here omitted.)

4. Testing.—The "Regulations for the Testing of Material for Rolling Stock" form, according to their applicability, a supplementary part of the following specifications.

To the inspector is to be given before the beginning of the inspection a list of the finished tires, ready for inspection, the list being arranged according to the order and the heats. The inspector will choose with the aid of this list and after inspecting the tires submitted, the tires, which will be tested.

(*a*) Drop Test.—For the drop test one tire from each heat will be chosen.

The tire is placed under the hammer on a support, which is correspondingly rounded; a similar piece is placed under the tup; the tire must flatten out under the blows of the hammer tup by an amount equal to $\frac{75}{100}\frac{D}{F}$ per cent of the original inside diameter, in which D represents the original inside diameter and F the lower tensile strength limit of the material type under test. The impact work of each blow shall be 3000 kgm. This flattening must be accomplished without any evidences of fissuring, and the blows are to be continued until the deformation has reached the above value; the last blow is, however, to be chosen of such an intensity that the required deformation is not much exceeded.

If the calculated amount of bend has not been reached without fracture, it is allowed to take from the tested specimen a tensile test specimen and determine the actual tensile strength, and if with this value of F in the above equation the deformation was great enough, it may be considered that the impact test has been passed.

Each tire under impact test shall finally be notched and broken. The fracture must show a dense and homogeneous structure.

(*b*) THE TENSILE TEST.—From each of the test tires subjected to the impact test shall be taken from that part least affected by the test, a test piece, which shall be straightened with moderate heating. From this shall be taken two tensile test pieces, one from the flange and one from the tread and subjected to the tensile test. The values obtained must satisfy the requirements above set forth.

(*c*) If the first test tire does not pass the drop test, two more tires shall be selected from the same heat and subjected to the same test. If either of these latter tires do not in any particular meet the specifications, all of the tires from this same heat will be rejected. If one of the tensile specimens of a tire which has passed the drop test does not fulfill the requirements of the tensile test, a repetition of the test is allowed. A second tire of the same heat is subjected to both of the above tests, and if only one of the specimens of this second test does not pass the test, notwithstanding that the tire has passed the drop test, all of the tires of this heat shall be rejected.

(*d*) The railway administration has the right to have parts of the tested tires subjected to a chemical analysis. The phosphorus content may not be more than 0.05 per cent. Heats, the chemical analysis of which is not satisfactory, may be afterwards rejected. The railway administration reserves the right to have etching and other tests made for the purpose of obtaining further information.

5. Further Regulations.—The "Supplementary Regulations for the Furnishing of Material for Rolling Stock" form an integral part of the preceding regulations.

SPECIFICATIONS FOR FORGED OR ROLLED WHEEL PLATES (1909)

1. Material, Manufacture, and Quality.—Wheel plates shall be of basic Martin soft steel (Flusseisen), of the best quality or of a material which is recognized by the consumer as being of equal quality. The method of manufacture is subject to the approval of the party ordering the wheel plates.

The wheel plates are to be suitably annealed.

There may be no flaws of any sort on the wheel plates, such as porous spots, fissures, etc.

2. Dimensions and Weight.—The wheel plates are to be made according to the data and sketches furnished with the order, and may be delivered as forged, rough machined, or in the finished condition. The normal weights of the wheel plates are given in the sketches, and excess weight of more than 3 per cent will not be paid for; excess of more than 5 per cent will not be allowed.

3. Marking.—All wheel plates receive on the inner surface, perpendicular to the axis, the following marks, in letters 4 mm deep, made, however, with tools which are not sharp-cornered: (1) Trade-mark of the firm; (2) year of delivery; (3) half-year of delivery; (4) number of the heat; (5) current manufacture number. To the inspector is to be given before the beginning of the inspection a list of the wheel plates to be inspected.

4. Testing.—The special regulations for the testing of materials for rolling stock form, according to their applicability, a supplement of these paragraphs.

One wheel plate of every heat in the rough, but annealed condition must be subjected to the following tests. The tests consist of the drop test and the tensile test.

(*a*) THE DROP TEST.—The test wheel is laid horizontally in a normal fall-hammer apparatus in such a way that it is supported at the periphery at all points over a width of about 10 mm uniformly, and is then struck at the hub by the hammer, and a suitable striking piece must be laid under the tup.

The impact work shall amount at the first blow to 1000 kgm, and shall be increased at each blow by 500 kgm as long as it does not reach the value of 3500 kgm, above which it does not need to be increased. Further blows are to be carried out with this latter maximum value when necessary. The drop test is to be continued until a bending at the center of 50 mm is reached.

(*b*) THE TENSILE TEST.—From every test wheel so tested in impact a tensible test piece shall be prepared; this is done by straightening (with moderate heating) and cutting out cold. The tensile test shall show a tensile strength of at least 42 kg per square millimeter and at the greatest 50 kg per square millimeter and an elongation of at least 18 per cent.

(*c*) If the test wheel first chosen shall not meet either of the tests, two more wheels of the same heat shall be chosen and tested in the same way; if either of these latter wheels fail to meet the requirements, the wheels of the whole heat must be rejected.

5. Supplementary Regulations.—The "Supplementary Regulations for the Furnishing of Material for Rolling Stock" form a part of the preceding specifications.

SPECIFICATIONS FOR SOFT CAST STEEL PARTS (FLUSSEISENGUSS WAREN) (1909)

1. Material, Manufacture, and Quality.—The material shall be only Martin soft steel or material known to the buyer to be of equal and of the best tough quality. The mode of manufacture is subject to the approval of the party ordering the articles.

The tensile strength of this material shall be at least 42 kg per square millimeter and not more than 50 kg per square millimeter with an elongation of 18 to 12 per cent, respectively, values between these to be linearly interpolated.

The phosphorus content may not be greater than 0.05 per cent.

The castings must be cast with coupons (Anguss) for test and analysis. The castings are to be annealed until the temperature stresses are removed. All castings must be without flaws, such as blowholes, fissures, etc., and must have a smooth surface. The coupons on wheel centers are to be left on until acceptance.

2. Dimensions and Weight.—The castings are to be made according to the data and the drawings furnished with the order. Locomotive and tender wheel centers shall be delivered either rough cast, rough machined (vorgeschroppt) or finished.

The specified weights must be adhered to as much as possible; excess weight of more than 3 per cent will not be paid for, and excess weight of more than 5 per cent is not permitted.

3. Marking.—(This article is omitted.)

4. Testing of Wheel Centers.—The "Regulations for the Testing of Materials for Rolling Stock" form, according to their applicability, a supplementary part of the following specifications:

(*a*) THE IMPACT TEST.—Each wheel shall be either as cast or as roughed, subjected to the drop test. In this test the wheel is lifted perpendicularly and allowed to fall on the rim such a distance that the impact work done amounts to 300 to 500 kgm.

The base of the fall hammer must have a weight of at least 4000 kg and at the point where the wheel falls a rail must be fastened to the base.

Each wheel center is to be tested twice in this way, the second time after being turned through a right angle.

In the case of wheel centers under 100 kg in weight the specifications are to be correspondingly changed.

(*b*) THE TENSILE TEST.—From two wheels of each heat, tensile test specimens shall be taken from the coupon (Anguss).

(*c*) A specimen for chemical analysis is to be taken from the cast-on piece of one wheel from each heat, and the results must satisfy the "Special Conditions For Testing Rolling Stock Materials."

(*d*) The official of tests is empowered to break the cast-on piece of each wheel center in order to gain an idea of the structure of the metal.

(*e*) FAILURE TO MEET THE TEST.—Wheels which fail to meet the requirements of the impact test, and fissure or break during the test shall not be accepted.

If one of the two tensile test specimens does not fulfill the specifications, two other specimens of the same heat are to be chosen and tested in the same way, but if either of these latter two does not meet the test satisfactorily, the whole heat shall be rejected.

If the chemical analysis is not found satisfactory, all wheel centers of that heat may afterwards be rejected.

(*b*) (This article deals with the testing of castings other than wheel centers.)

5. Supplementary Regulations.—The "Supplementary Regulations for the Furnishing of Material for Rolling Stock" form a supplementary part of the preceding specifications.

AUSTRIAN SPECIFICATION FOR CHILLED CAR WHEELS, PER CAR STANDARDS SHEET 18 (1910)*

For car wheel type $\frac{N}{07}$ the chill must penetrate from 12 to 20 mm. The treads must be ground perfectly round; variations of more than 1 mm are not permissible. The mounting pressure for chilled car wheels shall be at least 40 000 kg.

SPECIFICATIONS FOR CAR WHEEL PAIRS*

1. The two wheels of a pair must have accurately the same diameter, and excess of more than 5 per cent over the specified weight is not allowed.

2. Material, Manufacture, Quality, Marking, and Painting.—For regulations concerning the material and manufacture of wheel bodies, plates, centers, tires, and chilled car wheels, see the special specifications.

The wheel bodies are to be machined at the periphery and hub in the way shown in the sketches, and soft steel wheels for normal gauge track shall be pressed on with a pressure of at least 50 000 kg; for narrow gauge, with a pressure of at least 35 000 kg. Chilled cast wheels for normal gauge are to be forced on the axles with a pressure of at least 30 000 kg.

The tires are to be machined as in sketch and are to be drawn on to the wheel with a shrinkage of 1:1000.

The running surface of the chilled cast-iron wheels must be ground perfectly round.

After the tires are drawn onto the wheels they are to be machined as shown in the sketch.

Each wheel body must be balanced—that is, the center of gravity of the wheel must be located—and if it lies out of the center, a weight must be placed at the periphery to counterbalance it. Such a weight may not be more than 0.5 kg. Two wheels differing by more than 2 kg in weight may not be used on the same axle.

The wheels must receive the marks as shown in the sketch, trade-mark, name of owner, etc.

GENERAL REGULATIONS FOR THE FURNISHING OF MATERIALS AND EQUIPMENT FOR THE STATE RAILWAY ADMINISTRATION.*

11. Quality of the Materials and Inspection of the Manufacture—TESTS OF QUALITY.—(2) The railway administration reserves to itself the right to inspect, through its agents, the manufacture and preparation of articles furnished at the place of manufacture, to make tests of the quality of the articles or material, to have samples made and tested, and to inform itself at any time of the progress and quality of the work being done on articles to be furnished. The agents must therefore have at all times, during the manufacture of articles to be furnished, full access to that part of the plant engaged in this work, and must have full opportunity to inspect and inform himself concerning the manufacture of these articles. Material and apparatus must be furnished him for the purpose of making tests or measurements of any kind required or suggested in the specifications. The responsibility of the contractor for the quality of his product is not affected, however, in any way by this inspection.

HOLLAND

THE NORTH BRABANT RAILWAY[18]

Rails.—The rails are calculated for a wheel pressure of 7000 kg and have a weight of 33.7 kg.

The specifications for the Prussian State Railways hold for this latter material.

General.—The table below gives the physical properties of the material specified for axles, tires, and wheels.

Article	Variety of steel	Ultimate strength in tension	Elongation	Reduction of area
Carriages and cars:		Kg/mm²	Per cent	Per cent
Axles	Siemens-Martin steel	60–68	15–20	25
Tires	do	60–68	15–20	25
Wheel centers	(Vloeiyzer) soft steel	40–50	.....	.....
Spoked wheels	do	37–44	20	.....
Locomotives and tenders:				
Crank axles	Nickel steel	60–68	15–20	25
Other axles and tires	Crucible steel	60–68	15–20	25
Tires	Siemens-Martin steel	60–68	15–20	25
Tender wheels	Cast steel	38–45	20	.....

Axles—Tests.—One axle of each heat is submitted to the drop test. It is supported with a span of 1.50 m and is struck eight blows of 3000 kgm impact work for carriages and cars, of 5600 kgm for locomotives, and of 4200 kgm for tenders. The axle is turned 180° after each blow and must not break during this test.

Tires—Drop Tests—1. For Carriages and Freight Cars.—From each heat shall be taken one tire and submitted to a number of blows of 3000 kgm impact work. If the bending (flattening) is less than 10 mm, the blow must be increased by 500 kgm. The tire must be flattened by 12 per cent and not break.

2. For Locomotives and Tenders.—From each heat shall be taken one tire and tested in impact with blows of 3000 kgm. The flattening must be at least

$$E \text{ per cent} = \frac{D}{100} - \frac{d-65}{10}$$

where D is the diameter and d the thickness of tire. The flattening must be at least 12 per cent and on no tire less than 10 mm. In the latter case the impact work is increased by 500 kgm. The tire must not break by this test.

NETHERLANDS CENTRAL RAILWAY COMPANY[19]

General—1. Disk and spoke wheel centers for freight cars; forged disk wheel centers, passenger cars; forged spoke wheels, locomotives and tenders; cast spoke wheels.

2. Material and Physical Properties.—Requirements are the same as for North Brabant Railways.

3. Testing.—(See specifications for North Brabant Railways.)

[18] These specifications were received by letter of 1914 from this railway company.

[19] These specifications by letter from the Ministry of Railways, 1913.

STATE RAILWAY [20]

SPECIAL REGULATIONS FOR TESTING VARIOUS MATERIALS AND ARTICLES (No. 23, 1907)

Crank Axles for Locomotives.—MANUFACTURE.—The crank axles must each be manufactured out of one entire steel ingot of a dense and homogeneous structure, without welding, by forging or under the press.

The cranks must be forged from the full ingot, either directly bent into the proper position of the respective parts to each other, or forged straight and then bent, so that the proper parts come to a perpendicular position with respect to each other, as has been agreed on at the time of the contract. The material must be worked through and through, must be tough and sound, free from porousness, cracks, scale, and other faults. The fracture must exhibit a fine and uniform grain.

After being rough machined, each crank axle must be annealed, and thereupon slowly cooled.

MACHINING.—The crank axles must be smooth and clean over the whole length and be machined according to the drawings.

At the place where the hubs of the wheels or the outer cranks must be pressed on, the diameter of the axle must be left greater by 6 mm than the finished dimension.

The crank and bearing seats and collars must be polished smooth as a mirror, and each perpendicular cross section must be definitely circular. It is prohibited to work these parts with a file.

The center holes in the axle ends must be bored so deep before machining that they remain accurately according to the drawing; later boring of the center holes is not permitted.

TESTING.—In order to judge of the quality of the material, at least two bending and at least two tensile test specimens shall be taken from each axle. All crank axles must for that purpose be forged so much longer that on one end a sufficient length may be left for the preparation of the test bars, which are to be taken both from the core and from the outer part of the axle.

The tensile test specimens consist of cylindrical bars of diameter of 20 mm extending over the test length of 200 mm and 10 mm farther. The fillet at the test head shall be machined smooth.

The results of the tensile test must satisfy the following conditions:

	Nickel steel.	Steel (Kroe-zen).	Special Siemens-Martin steel.
Elastic limit in kilograms per square millimeter, at least.	40	32	30
Tensile strength in kilogram per square millimeters, at least	60	55	55
Elongation in per cent, at least	18	20	20
Reduction of area in per cent, at least	40	45	50
Sum of elongation and tensile strength, at least	80	78	78

The bending test specimens shall have a square section 30×30 mm; and the sharp angles must be rounded with a radius of 1.5 mm. The specimens shall have a test length of 200 mm. They must be capable of bending cold through 180° (double), so that the ends touch each other without cracks or other faults.

If the test taken with one crank axle be not satisfactory or only partly so, the axle shall be rejected.

MARKING.—(Omitted.)

[20] These specifications were received by letter of 1913 from the Ministry of Railways.

GUARANTEE.—For each delivered crank axle the manufacturer shall guarantee 165 000 km, which the axle must run under the locomotive, without breaking, failing, or showing any other fault. The manufacturer is bound to furnish a new axle satisfying all of the conditions of the specifications for each old one, which may have been put out of service, because of any fault before it had run at least 165 000 km, without cost to the railway, and this must be done as quickly as possible after the receipt of the notice of the failure of the old axle, within 3 months at the very latest.

PACKING.—(Omitted.)

SPECIFICATIONS FOR MOUNTED WHEELS (1911)

(Contract form is omitted.)

General—Material.—The axles and tires shall be of the best quality of Siemens-Martin steel, the wheels and spring rings of the best quality wrought iron (Welijzer) or Siemens-Martin steel (Smeltijzer), as is more definitely described in the contract.

In the bids the kind of material and mode of its manufacture must be given.

Axles.—The axles shall be forged by hammer or press, each from one whole steel ingot of dense and homogeneous composition without joining or welding. They are then annealed and allowed to cool slowly. The center cross section of the ingot must be at least four times that of the rough axle.

The axles must be turned smooth over their whole length, and must be cleanly round. Sharp shoulders are not permitted. The finished axles must be sound and smooth, and must not show scale, porosity, rough places (scheurtjes, schilfers, ruwe plekken), or other flaws; sharp fillets in the diameter must be avoided.

The machining of the wheel seat before pressing the wheels onto the axle must be done from the nearest end. The parts of the wheel seat must be manufactured so as to be smooth and sound; roughness (draairingen) from machining must be avoided.

The journals, necks, and collars must be polished with mirrorlike finish; working them with the file is forbidden. The cross section of the journals perpendicular to the axis of the axle must be cleanly round all over. The axles must be well centered. The center holes must be bored before machining so deeply that they remain in the finished axle in the exact position given in the drawings. Subsequent boring of these center holes is forbidden.

(There is here omitted a paragraph dealing with the marking of the axles.)

TESTING—*Drop Test.*—One axle of each lot of 50 or less, at least one of each heat, shall be chosen for test. These axles, roughed or finished, are submitted to the drop test. Each axle is placed on firm saddlelike supports, 150 cm apart, fastened to an anvil of iron of at least 10 000 kg weight. The supports on which the axles rest are saddle-shaped, with a semicircular cross section of radius of 50 mm. The hammer tup must fall freely without friction; the blows are to be directed at the center of the axle. The impact work of each blow shall be 3000 kgm, and the axles must withstand four blows in the same direction, and as many more as are necessary to bend the axle by 20 cm (200 mm). In this process the axles must show no fissures and must not break.

During the test the axles must not be turned over, but must be bent in the same direction at each blow. After each blow the amount of bending is to be measured, and at the last blow the fall height is to be adjusted according to the amount of bending yet to be accomplished.

The bending must be measured on the upper edge of the axles, and each time with respect to the distance between the supports. In measuring the amount of bending, use may be made of an instrument having the form of a semicircular compass, with a movable slide at the center, calibrated in mm and perpendicular to the circular rod of the compass.

The drop test may be continued until the axle breaks; if necessary, the axle may be notched so that it may be broken. If the test of one axle is not satisfactory, or only partially so, then two other axles of the same heat may be offered to the inspector for test. If these, or only one of them, do not comply with all the requirements, then all of the axles of the same heat shall be irrevocably rejected. During the drop test the temperature of the axles shall be noted.

The Tensile Test.—From each axle tested under the fall hammer a piece is to be taken, from which, after the heat number has been taken from the inspector's stamp at least two test bars 200 mm long and 20 mm in diameter are to be taken from the center of the cross section. The tensile strength must be from 52 to 60 kg per square millimeter, the elastic limit at least 30 kg per square millimeter, the elongation over the test length of 200 mm at least 20 per cent, and the reduction of area at least 30 per cent of the original area.

If the tests with one of the two test bars taken from the same axle are not satisfactory, or only partly so, there shall be taken from the same axle, which must, however, first be provided with an inspection stamp, two more test bars of the same dimensions. If the test on both of these bars does not fulfill all conditions, all of the axles of the same heat will be irrevocably rejected.

Wheels.—The iron to be employed in the manufacture of wheels must be dense, easily forged, tough, neither cold nor hot short, free from slag, porosity, fins, cavities, and other faults (slakken, schilfers, bladders, laschnaden, kantscheuren). For welded wheels the material must be easily weldable.

The mode of manufacture of the wheels must be given in the bid. Cast plate wheels are not accepted.

In the case of forged or welded spoke wheels, the hub, the spokes, and the rim must be joined together into a whole piece and worked clean, sound, and smooth. No traces of burning may appear. The spokes of the wheels must be of uniform thickness and carefully adjusted. They have to be worked so that no unevenness may appear. At the place where the plates join with the hub or the rim the wheel must be machined smooth, as in the drawing.

The rim of the wheels must be cleanly smooth on its periphery, and on both sides must be machined according to the dimensions and have the same cross section over the whole periphery. Both end faces of the hub, the hub bore, and the cylindrical outside face must be machined.

The machining of the hub bore before the pressing of the wheels on the axles must be done from the inner face. The bore must be machined soundly and smooth.

Machining roughness (draairingen) must be avoided.

The inner diameter of the hub of the wheels must be so much smaller than the diameter of the axle at that part of the hub that the wheels may be pressed onto the axle by a gradually increasing pressure of at least 60 000 kg, and at most 90 000 kg.

(There is omitted a paragraph dealing with the marking of the wheels.)

Testing of the Wheels.—From the number of wheels offered for test in the case of spoke wheels, 2 per cent shall be taken, with a minimum of 1 wheel. In the case of plate wheels 1 wheel from each 50 wheels, or part of 50, of the number offered for test, but at least 1 wheel from each heat shall be chosen for test. At least 50 wheels are to be offered for test at one time, unless otherwise provided for.

Hub Bore Expanding Test.—The wheel to be tested is placed upon wooden supports, with one of the side faces of the rim being perfectly level. A four-segment mandrel, with a square opening in the center, is shoved into the bore. Into this opening a steel wedge of the form of a truncated regular square pyramid of a conicity of 1:20 must fit completely.

This wedge is to be driven in by 6 blows, whereby the product of the fall weight in kilograms and the fall height in meters shall be successively 300, 400, 500, 600, 700,

and 800. After this test the wheel must not show any cracks or other flaws. The wheel may then be broken.

Before being employed in this test, the wedge and the inner sides of the mandrel are to be oiled and then wiped dry.

If the wedge tests taken with one or more wheels are not satisfactory, then the testing official may take for test a double number of the spoke wheels first tested, which had not been satisfactory, or two plate wheels, respectively, of the same heat. If these do not fulfill all conditions, or if only one of them does, then all of the spoked wheels offered for test or all plate wheels of the same heat shall be irrevocably rejected.

TENSILE TEST.—From the wheels thus tested three test bars are to be prepared and tested, one from the hub, one from the spoke or plate, and one from the rim, after they have first been marked. The diameter of the cylindrical test bars shall be as nearly as possible 20 mm. In the case of test bars with a square cross section, this cross section is to be about 300 mm^2, and the test length, about 200 mm, or as near to that value as possible. The material of the wheels must satisfy the following conditions:

Material	Tensile strength, in kilograms per square millimeter, of the original cross section	Elongation, in per cent, of the 200 millimeter test length
Wrought iron for forged spoke wheels	At least 34	At least 12.
Siemens-Martin steel for forged spoke wheels	34 to 41	At least 25.
Siemens-Martin steel for plate wheels	40 to 50	At least 20.

If the tests with one or more test bars taken from the same wheel are not satisfactory, or only partly so, then from that lot from which the test bars were taken two others of the same dimensions may be prepared, after the stamp of the inspection has been provided. If the tests taken with both of these bars are not satisfactory in all respects, all of the spoked wheels offered for test or all of the plate wheels from the same heat shall be irrevocably rejected.

EQUILIBRATION.—For this purpose each wheel, after forcing upon the axle according to the requirements of the first part, in the factory of the contractor, is to be placed upon two steel-bar supports, smooth, horizontal, and of uniform width and height. The weight which has to be applied to the rim of the wheel in order that the center of gravity may be in the geometric axis may be not greater than 0.5 kg.

Tires.—Each tire must be manufactured from one entire steel ingot of a dense and homogeneous structure, without welding or joining, by means of hammers or presses and rolls. After the rolling out of the tires they must be appropriately protected against sudden cooling. The tires must not show any faults of rolling, fins, cavities (scheuren, bladders), or other faults. The manner of preparing the material, as well as the method of manufacture, of the tires must be explained to the inspector on request.

(There is here omitted a paragraph dealing with the marking of the tires.)

The inside upper face of the tire and the grooves for the fastening of the same onto the wheel center are to be machined smooth, according to the sketches and sharp fillets must be avoided. The inside diameter of the tire must be smaller than the outside diameter of the wheel by so much that the shrinkage measure may be 1 mm for each meter of inside diameter.

The material must be so tough that upon being shrunk onto the wheels the tires will not show any cracks, fracture, etc.

The heating of the tires before their cooling after being shrunk on must be done in such a manner that the tire will retain the same degree of hardness all over which it had before the heating.

This heating shall not cause the diameter to become more than 2 mm larger than that of the cold tire.

TESTING OF TIRES.—One tire of each 50 tires, or part of 50, of the number presented for inspection, but at least 1 tire from each heat is to be offered to the inspector for testing. Not less than 50 tires are to be offered for test at the same time, unless otherwise provided for.

The Drop Test.—The tires are to be subjected to drop tests, and for this purpose are to be placed under the hammer tup on a support, which is fastened on a foundation block of iron weighing at least 10 000 kg. On the upper part of the test tire, where the tup is to fall, there is to be placed a piece of at least 20 kg in weight, flat on the upper side and having approximately the profile of the tire on the lower side. The cover piece and support are to be curved with a radius of about 150 mm on that side which comes in contact with the tread surface. The tup must fall freely without friction. During the drop test the temperature of the tire is to be taken.

The product of the numbers giving the fall height in meters and the fall weight in kilograms must be 3000. The wheel tires receive at least four blows at the center of the tread surface, or so many more as may be necessary to produce a reduction of at least 12 per cent in the original inside diameter.

When the prescribed reduction of the diameter has been reached, the tires must not show any cracks or fracture, and must not be broken. After each blow the diminution of diameter is to be measured. The drop test may be continued until the tire is hammered flat or until it breaks. If necessary, the tire may be notched in order that it may be broken.

If the tests taken with one tire be not satisfactory, or only partly so, then two more tires of the same heat may be offered to the inspector for testing. If these, or one of them, do not comply with all conditions, all of the tires of the same heat shall be irrevocably rejected.

Tensile Test.—From each tire which has been tested in the drop test at least two tensile-test pieces are to be prepared from that part of the tire which has suffered the least (at the choice of the manufacturer), and as far as possible from the center of the cross section. These shall have a test length of 200 mm and a diameter of 20 mm.

The material for the preparation of these test bars must not be warmed or heated, unless it be unavoidable, and in that case not more than is strictly necessary for the obtaining (bending) of the specimen.

The tensile strength must be at least 55 kg per square millimeter, the elastic limit at least 32 kg per square millimeter, the elongation at least 18 per cent of the 200 mm test length, and the reduction of area at least 30 per cent of the original cross section.

If the tests taken with one or more test bars from the same tire are not satisfactory, or only partly so, two more test bars are to be prepared of the same dimensions from the same tire, which must be first provided with the testing stamp. If the tests made with both these bars do not fulfill all conditions, all of the tires of the same heat shall be irrevocably rejected.

Spring Rings.—(Omitted.)

Testing of Spring Rings.—(Omitted.)

Mounting of Wheels.—(Omitted.)

FAULTS.—It is forbidden to cover up faults in the material or in the method of manufacture in any way.

INSPECTION.—The contractor shall furnish all of the tools, apparatus, measuring instruments, and personnel necessary without cost, and must bear all of the cost of renewal of parts broken during the test.

The railway company has the right to manufacture the minor parts and to assemble the wheel in the shop of the manufacturer, through one or more persons, who direct the work. These persons must have at all times free access to the shops when the

axles, wheels, tires, and spring rings are being made and worked, or where the minor parts are being assembled. They are wholly free in the inspection of the pieces to be tested, and are authorized at any time to make a test which they consider necessary.

The equilibrating of the wheels, the shrinking of the tires onto the wheels, and the pressing of the wheels onto the axles take place in the presence or one or more persons designated by the railway company.

Deviations in dimensions are not permissible; all measuring must be controlled carefully by means of templets, compasses, etc.

REJECTION.—(Omitted.)

STAMPING AND PAINTING.—(Omitted.)

PACKING.—(Omitted.)

DISPATCH.—(Omitted.)

DELIVERY.—(Omitted.)

TRANSPORTATION.—(Omitted.)

PRICE AND CONDITION OF PAYMENT.—(Omitted.)

Guarantee.—For three years, beginning with the day of delivery, the contractor shall be responsible for the serviceability of the material, the workmanlike manufacture and assembling of the parts, with the understanding that the contractor is bound to bear all of the costs of manufacture or renewal which are the result of poor quality of the material or of the faulty method of manufacture or carelessness in the assembling of the parts.

Arbitration.—(Omitted.)

HOLLAND RAILWAY

SPECIFICATIONS FOR THE DELIVERY OF STEEL RAILS (1913)

1. Dimensions and Weight.—The rails must agree in form with the designs and the templets made from them. The profile must be preserved over the whole length, and no damage may be done to it in the cutting of the rails; at the ends of the rails the burrs must be removed.

The normal length of the rails shall be, at a temperature of 10° C.:

14 m for a rail height of 130 mm, profile H. IJ. S. M.

9.62 m for a rail height of 128 mm, profile S. S.

9.0 m for a rail height of 120 mm, local.

The number of rails of other lengths than normal to be delivered shall be given in the contract.

In rails of length of 9 m and less the allowable tolerance shall be $\pm$ 2 mm, that in rails of over 9 m in length $\pm$ 3 mm. In order that these measurements of length shall be made accurately, there shall be kept near the rail bed a steel tape, protected from the heat and the weather, and graduated in millimeters, with which the rule or tape used in measuring the lengths of rails may be compared. To the testing official shall be furnished all of the models or templets which are required in each measurement, and particularly in the measurement of the positions and dimensions of the tie-plate and other holes, and of the slopes of the base of the rail.

There will be allowed in the width of head a tolerance of 0.5 mm, in the width of base of 1 mm, in the position of bolt holes 0.5 mm at most.

The rails of normal length require no special marks, those of height of 130 mm and length of 13.93 m, those of height of 128 mm and length of 9.555 m, and those of height of 120 mm and length of 8.90 m to be used in curves must be painted red on the end face, while in all other rails the length is to be indicated in painted figures above the head and on the side of the web. Rails with sloping bases must be painted white on the end faces.

The normal weights per meter for the rail bar shall be—

38.6 kg for the height of 130 mm, profile H. IJ. S. M.
52 kg for the height of 130 mm, profile H. IJ. S. M., eccentric.
33.7 kg for the height of 128 mm, profile S. S.
25.6 kg for the height of 120 mm, local.

A tolerance in this weight will be allowed for partial lots of 2 per cent more or less, but the total actual weight of the whole lot shall be within 1 per cent of the normal weight.

Within these limits the rails shall be paid for according to actual weight. If below this weight, they shall be refused; if above this weight, they shall be accepted; but the contractor shall not be paid for the overweight.

2. Manufacture of the Rails.—The steel from which the rails are manufactured shall be of Martin, of Bessemer, or of the improved Thomas process.

In order to facilitate for the inspector the investigation of the steel, the manufacturer must at all times allow the former to examine all of the lists or tables in which the results of tests taken in the factory itself are entered day by day, and wherein an account is kept of the carbon content as well as of that of other qualities of the steel.

The ingots to be rolled must have the greatest possible cross section, and be so heavy that they furnish at least two rails of normal length with discards of not less than 0.50 m.

Before an ingot is put into the rolls it shall be carefully inspected on all sides, and all surface roughness, such as scale, porous spots, fins (schalen, schilfers, bladders, dorens), etc., shall be removed.

At the request of the inspecting official the heat numbers shall as far as necessary be stamped on some of the rails in easily visible figures. The rails shall, moreover, be provided with other marks upon request.

3. Quality of the Rails.—The rails must be sound and smooth; those rails showing traces of burning or of cracks or other faults of a harmful nature shall be refused. The ends must be completely sound and freed from the milling or sawing burr, so that the tie-plates may lie flat on the web faces.

The rails must be completely straight over the whole length. The straightening must be done by hand or steam presses with a slowly increasing pressure and not by hammering, so that there shall remain no visible marks of the gagging, either in the horizontal or in the vertical direction. In the base of the rail no curvature or fault will be tolerated. These requirements apply even more rigidly to the nonsymmetrical rail type H. IJ. S. M.

The rails must show the exact profile required, for which purpose the rolls after having rolled 1000 tons of rails at most must be inspected, and if any deviation be noticed, renewed.

The rails are to be milled at both ends, so that the end faces are clean and perpendicular to the axis of the rail bar; the burr shall be carefully removed with chisel or file.

It is expressly forbidden to reheat the rails, to hammer or to file them in order to cover up some fault of manufacture. Rails treated in such a way will be refused.

The rails shall be provided as far as necessary with holes in the web and base slope, the number, position, form, and dimensions of which are to be indicated on the proper drawings.

The holes must be bored; they must have clean and smooth surfaces, be perpendicular to the side of the web, and freed from the burr.

The slope of the base of some of the rails must be brought about by machining over length and breadth, and it shall be perpendicular to the lower base surface.

If the dimensions, condition, form, or position of these holes or slopes do not agree with the drawings the rails will be refused.

4. Testing of the Steel.—From the various heats used in rolling rails one test ingot may be taken, and the carbon and other content determined.

Not until after the first heat for rails has been rolled and then tested in regard to toughness, ductility in bending, and strength shall the limits be decided within which the carbon content and content of other constituents must be kept.

Bars of thickness of 20 by 20 mm, forged from the test ingot, must be capable of being bent cold without fracturing, so that the ends shall come together at a distance equal to five times the thickness.

In general, the material from which the rails are being manufactured shall exhibit the qualities of good and serviceable steel in all respects; it must be tough and ductile in bending and must show a dense, fine, and bright grain in the fracture.

5. Testing of the Rails.—The official charged with the tests shall after investigating the quality of the steel select a number of rails up to 1 per cent at most of the partial lot manufactured at that time, and belonging to the same heat, and subject them to the following tests:

(1) The Tensile Test.—From the head of the rail bar a test bar is to be taken cold, of a uniformly circular cross section over a length of 200 mm at least, and of a diameter of 20 mm at least. It must withstand a tensile stress of at least 60 kg and at most 70 kg per square millimeter of the original cross section, while the elongation at the moment of fracture must be at least 15 per cent.

A rail bar notched 2 mm deep on the head and placed with the head on two immovable supports must be slowly broken by the application of pressure by means of a hand-screw press, and not by a power press. The rail shall be broken also in the reverse direction in like manner, the rail being notched on the base.

The fracture must exhibit a completely uniform, bright, and fine grain. In polishing and etching the fracture surface the steel must appear perfectly dense and free from slag and porous spots.

(2) The Transverse Bending Test.—One-half of the rail bar broken in the manner above specified, resting on two immovable supports, which are to be placed at a distance of 1 m from one another, shall be subjected at the center to a weight of the following amount for five minutes:

20 000 kg for the rails of height 130 mm, profile H. IJ. S. M.
25 000 kg for the rails of height 130 mm, profile H. IJ. S. M., nonsymmetrical.
16 500 kg for the rails of height 128 mm, profile S. S.
13 000 kg for the rails of height 120 mm, profile local.

After removing the load there shall be no permanent deformation or bending.

The rail bar resting on the same supports must not break after having been subjected to weights of two and one-half times the preceding ones for the same length of time.

(3) The Drop Test.—The second half of the same rail bar must be able to withstand the first blow of a drop hammer of the following intensities:

4200 kgm for the rails of height 130 mm, profile H.IJ.S.M.
4900 kgm for the rails of height 130 mm, profile H.IJ.S.M. nonsymmetrical.
3900 kgm for the rails of height 128 mm, profile S. S.
3200 kgm for the rails of height 120 mm, profile local.

In this test the hammer tup falls at the center of the span. The amount of bending under the first blow must not exceed 65 mm; thereafter the test shall continue with blows of 1800 kgm until a total bending of at least 100 mm shall be attained without the rail breaking.

The hammer used in this test shall have a tup rounded with a radius of 5 cm, and may be raised higher in order to carry the test to destruction.

If in this test one of the rail bars does not fulfill the prescribed conditions, or the fracture exhibits faults in the quality of the steel, then a second rail bar is to be tested in the same way. If this second bar does not give satisfactory results, the whole lot of rails manufactured at the same time and of the same heat shall be rejected.

On the other hand, if the second rail bar withstand the test, then two more rail bars shall be subjected to the test; if they also fulfill the specifications of the test, then the whole lot shall be accepted; but if only one of the two fulfill the conditions of the test the whole lot shall be rejected.

In order that no differences may arise concerning the results of the tests the manufacturer shall have an official agent present, whenever an official of the railway administration undertakes a test, so that he may corroborate the results of the test.

A record of the result of the tests shall be made.

6. Templets.—(Here omitted.)

7. Identification Marks.—(Here omitted.)

8. Supervision.—The administrative board reserves to itself the right to supervise the manufacture of the rails through one or more officials.

The manufacturer is bound to give notice 14 days in advance of the day when the manufacture is to begin, and to furnish to the officials of test all information required both relating to the arrangement and use of the apparatus, tools, furnaces, etc., and to the manufacture itself.

These officials shall be charged night and day to oversee the manufacture in all particulars, and to undertake any investigations which may be necessary to insure a strict compliance with all of the provisions of these specifications. They reject the poor rails, which must be taken back without any claims for damages.

The investigation, the testing, and the weighing is done at the cost and risk of the manufacturer in his plant, where the accepted rails are stamped and the rejected ones are painted on both ends with red paint.

The delivery is to take place only during dry weather, and the rails shall lie before that time in dry, covered places, provided with a sufficient number of openings for the light. (From here on this paragraph is not complete.)

The weighing is done with 10 per cent of the rails of each partial lot for delivery.

(Other paragraphs follow dealing with the time of delivery, the power of the inspector, storing of the rails, rusting of the same during storing, etc., which are here omitted.)

9. The Factory.—It is expressly forbidden to assign any part of the contract for delivery to any other firm or contractor, or to have any part of the materials or articles contracted for manufactured in any other plant without the consent of the railway administration.

10. Default.—(Here omitted.)

11. Fines.—(Here omitted.)

12. Guarantee.—The manufacturer remains responsible for the rails for five years after delivery, counting from the time when the rails have been placed on the track. The time at which the guarantee begins is the date of the record of acceptance; during that period the manufacturer shall at the first request of the railway administration take back all rails in which any cracks or other faults manifest themselves, or which break, and replace them with other rails in accordance with these specifications.

If the manufacturer does not replace such rails within two months after notice has been given, the board shall have the right to buy at the cost of the manufacturer such rails wherever they deem proper.

13. Delivery and Penalties.—(Here omitted.)

14. Payment.—(Here omitted.)

SPECIFICATIONS FOR ROLLING STOCK, 1913 (BY LETTER)

A. Wheel Pairs for Locomotives.—The wheel pairs are to be delivered finished and ready for service. The materials to be used are the following:

(1) Axles, of Martin steel: Tensile strength at least 50 kg per square millimeter; elongation at least 18 per cent.

(3) Wheel centers, of cast steel: Tensile strength, 38 to 45 kg per square millimeter; elongation at least 25 per cent.

(4) Tires, of crucible steel: Tensile strength 70 to 90 kg per square millimeter; elongation at least 14 to 18 per cent; and the tensile strength of $(70+x)$ kilograms per square millimeter must be associated with an elongation equal to $(14-6\ x/20)$ per cent.

(7) The crank axles are to be of nickel steel. (See E.)

B. Wheel Pairs for Tenders.—The physical properties are indicated below:

(1) Axles, of Siemens-Martin steel: Tensile strength 50 kg per square millimeter; elongation 18 per cent.

(2) Wheel centers, of cast steel: Tensile strength 38 to 45 kg per square millimeter; elongation 25 per cent.

(3) Tires, special Martin steel: Tensile strength 65 to 80 kg per square millimeter; elongation 15 to 10 per cent; and the last material shall show an elongation of at least $(15-x/3)$ per cent with a tensile strength of $(65+x)$ kilograms per square millimeter. The phosphorus content of this special Martin steel shall be less than 0.04 per cent.

The wheel pair must be perfectly equilibrated.

C and D. Wheel Pairs for Passenger and Freight Cars.—The required physical properties are indicated below:

(1) Tires, of Martin steel: Tensile strength 60 to 75 kg per square millimeter; elongation at least 15 to 10 per cent. In this case the elongation associated with a tensile strength of 60 kg per square millimeter must be at least 15 per cent; that with a tensile strength, of 75 kg per square millimeter at least 10 per cent, and must have corresponding values for intermediate values of the tensile strength (linearly interpolated; this method of construing a requirement for the tensile test, when two values are given, as above, is used throughout this specification.)

(2) Axles, of Martin steel: Tensile strength at least 50 kg per square millimeter; elongation 18 per cent.

E. Crank Axles of Nickel Steel.—Nickel content must be 5 per cent, the tensile strength at least 60 kg per square millimeter, and the elongation at least 18 per cent.

F and G. Straight Axles for Locomotives, Tenders, Passenger and Freight Cars.—These shall be of Martin steel and must be annealed after forging. The required physical properties are indicated below:

Tensile strength at least 50 kg per square millimeter; elongation at least 18 per cent.

H. Locomotive Wheel Tires.—The required physical properties are given below:

Tensile strength 70 to 90 kg per square millimeter; elongation 14 to 8 per cent.

I. Locomotive and Tender Wheel Tires of Special Martin Steel.—The required physical properties are given below:

Tensile strength 65 to 80 kg per square millimeter; elongation at least 15 to 10 per cent.

The phosphorus content shall be less than 0.04 per cent.

J. Martin Steel Wheel Tires for Passenger and Freight Cars.—The physical properties are given below:

Tensile strength 60 to 75 kg per square millimeter; elongation at least 15 to 10 per cent.

Further Regulations for Wheel Pairs.—The wheel pairs shall be delivered ready for use. The journals must be finished, polished, and protected against damage and rust during transport. The axles and tires are to be made of Martin steel, the wheel centers and spring rings of rolled or hammered soft steel. The outer diameter of the finished wheel body as well as the inner diameter of the cooled tire shall be finished to the exact dimensions given in the design. The shrinkage measure shall be at the maximum 1 mm and the pressure with which the wheels are forced onto the axles at least 70 (metric) tons.

The axles, tires, disk centers, and spring rings are to be inspected before they are assembled. From every lot of 50 tires, 50 axles, or 100 disk centers shall be chosen one for purposes of test.

The tests to be carried out are: (*a*) For the axles, tensile tests; (*b*) for the tires, partly drop tests, partly tensile tests, according to the inspector; (*c*) for the disk centers, drop tests. From every test sample chosen for the tensile tests there shall be taken at four places indicated by the inspector or official of tests, four test specimens; two of these are to be prepared according to a design furnished to the company and sent to the central shops of the Dutch Railways at Haarlem, where they are to be tested. If this test does not furnish favorable results, a further test on the other two specimens shall be made in the company's shops.

The drop tests of tires and disk centers shall be made in accordance with the regulations of the Royal Prussian State Railways.

Special Regulations for the Furnishing of Wheel Tires.—The wheel tires shall be furnished unmachined. (For testing of tires see above.) The variation from perfect roundness in the tires may not be more than 2 per cent.

SWEDEN

STATE RAILWAYS

RULES FOR THE MANUFACTURE AND DELIVERY OF RAILS OF THE —— MODEL (MARCH, 1912)

Material.—1. Rails shall be made of steel produced by the ——— Martin method, or the ——— Bessemer method. The phosphorus content shall not exceed 0.075 per cent.

HARDNESS TEST.—2. The material shall have a tensile strength of at least 60 kg per square millimeter. In testing the hardness of the rail head with a hard steel ball of a diameter of 19 mm and a pressure of 50 000 kg, an impression should be obtained of a depth not less than 3.5 and not more than 5.5 mm. The finished rail shall sustain the following test at a temperature of +15° C:

3. The rail shall be laid, head upward, upon two supports of cast iron or steel, placed at a distance of 1 m from each other, firmly clamped to a bed (substructure) weighing at least 5 tons, and submitted to a blow, at the middle of the supports, of a weight of 1 metric ton falling from a height of 5 m, and then to repeated blows with the same weight from a height of 1.2 m until the bending of the rail shall amount to 100 mm. No trace of cracks or other defects should be visible.

Manufacture.—1. From both ends of the rail rolled from each ingot pieces of sufficient length shall be cut off so that the ends of the rail shall be completely free of defects. The piece taken from that end of the rail which corresponds with the upper end of the ingot shall be at least 2 m long.

2. The rails shall have an even and smooth surface and shall be free from flaws, cracks, and other defects of the surface. To repair or conceal such defects by hammering or other means is prohibited. Flaws of less than 1 mm in width may be chiseled away, but only on special permission by the inspector in each particular case, and in no case on the rail's ends or on the upper lateral roundings of the rail head.

3. Rails shall be rolled in strict compliance with the sketch. A deviation of ±0.5 mm in the height of the rail and the breadth of the head, and ±1 mm in the width of the base is allowed.

4. Rails shall be perfectly straight and free from warp. After cooling they shall not be heated any more, and only slight straightening may be undertaken, to be carried out carefully, so that the tools may leave no marks or impressions.

5. The end surfaces shall be plane and straight and perfectly perpendicular to the longitudinal axis of the rail. All cuts due to sawing or machining are to be carefully smoothed away.

6. Each rail shall be provided with two bored holes at each end in strict compliance with directions. The burrs due to boring shall be smoothed away carefully.

Length.—1. The length of the rails shall be —— m at a temperature of +15° C, with a permissible variation of ±3 mm.

2. In the case of rails for curves, —— per cent of the total lot shall be delivered in lengths of —— m. These rails are to be marked with white paint. Up to 5 per cent of the whole lot is to be delivered in lengths of —— m, which rails shall be marked on both ends with green paint.

Weight.—1. The rails shall have a normal weight of —— kg per meter, as provided in the contract. Deviations of ±2 per cent for an individual rail and of ±1 per cent

for the whole lot are permitted, but excess weight over the normal will not be paid for. In the case of underweight within the prescribed limits, the actual weight will be paid for. The contractors are responsible that the actual weight shall not fall below the specified limits.

Marking.—Each rail shall bear the name and stamp of the manufacturer, the year of manufacture, and the letters S. J., in letters and figures 20 mm high. Immediately after rolling each rail shall be stamped with the number of the heat from which it was rolled.

Inspection and Testing.—1. The manufacturer shall keep and furnish to the inspector an account of all heats employed in the rolling of rails.

2. A chemical analysis for carbon and phosphorus content shall be made of each heat (utslag), with a complete analysis of each tenth heat, or oftener, if the inspector shall deem it advisable.

3. A hardness and a drop test, as required above, shall be made on at least one rail of each heat, with a static tensile test as often as the inspector may consider it desirable.

4. If a rail does not comply with the specifications for drop test and hardness, as indicated above, two other rails shall be selected from the same heat and tested in the same way, and if neither of them fulfill the specifications, all of the rails rolled from that heat shall be rejected.

5. Each rail inspected and passed shall be stamped by the inspector with a special stamp; without this stamp rails shall not be accepted.

6. During the manufacture of the rails the inspectors shall have access to the plant where the manufacture is taking place, and the manufacturer is obliged to place at their disposal, without cost, not only the rails, tools, and apparatus, but also the men needed for the tests.

7. The manufacturer is obliged to notify at least —— in advance the supply bureau of the Royal State Railways Administration of the rolling of each lot of rails contracted for.

REGULATIONS FOR THE DELIVERY AND MANUFACTURE OF AXLES AND WHEELS FOR LOCOMOTIVES (1913)

The axles should be manufactured of first-class Martin steel, free from defects, in accordance with the best practice, from Swedish pig iron which is free from flaws and other defects.

Material for the axles shall have a tensile strength of at least 50 kg per square millimeter and an elongation of at least 20 per cent over 50 mm test length. The yield point must not be below 28 kg per square millimeter, and the reduction of area shall be at least 35 per cent of the original area. Axles shall be machined over their whole length and the ends polished. Materials for crank axles shall contain at least 3 per cent nickel and shall have a tensile strength of at least 55 kg per square millimeter and an elongation of at least 20 per cent over 50 mm test length. The yield point shall not be below 40 kg per square millimeter, and the reduction of area shall be at least 40 per cent of the original. Test specimens shall be taken from both crank ends of all crank axles in accordance with sketch number 5438. For straight axles there is required a test specimen from one axle of each heat. Axles shall be well annealed after forging and allowed to cool slowly. The journals shall be turned in the lathe. An axle which is delivered with the wheel must have the wheel seat worked smooth, and must have the diameter at the outer end less than that of the journals by 0.4 mm or less. The wheel seat of axles furnished without wheels shall be left rough and with 5 mm machining leeway, measured along the radius. The manufacturer of the axles must be one recognized by the Royal State Railway Administration.

The wheels shall be cast of soft Martin steel of the best possible quality in accordance with the specifications of the Royal State Railways, and they must be manufactured

carefully according to measure so that each counterweight, hub, etc., has the proper dimensions. The counterweights shall be turned to their proper thickness and the hubs of the wheels shall be turned smooth at both ends.

The spring rings shall be turned according to the profile and to the correct diameter. The holes in the wheels for the taps (tapparna) shall be bored in the mill after the wheels have been pressed on the axle.

The tires shall be made according to the special specifications. They should be put together in such a manner that the difference in carbon content should not be more than 0.05 per cent between the tires on the same axle or between the wheels of the same driving or coupling axle. They should be turned on both sides according to profile, with a shrinkage measure of 1/1000.

The end surfaces of the tires shall be machined smooth and be provided with grooves for the reception of the wheel and spring ring. The tires shall be machined on the tread surface after they have been mounted on the wheel. The diameter at the tread circle of a wheel set, mounted on the same coupling or driving axle, shall be the same. The hammering down of the opening for the spring rings shall be done carefully, especially at the groove.

The forcing of the axles onto the wheels shall be done in a hydraulic press with the greatest care, using a pressure of from 5 to 6 metric tons per centimeter of the inside diameter; a record of the process of the final forcing shall be sent to the machine-inspection bureau of the Royal Railways.

Driving and coupling axles shall be forged of nickel steel for which the regulations above for nickel steel for driving axles are applicable.

Test specimens are to be round and have a diameter of 10 mm.

(Paragraphs dealing with the marking of the various articles follow, which are here omitted.)

SPECIFICATIONS FOR ROLLING STOCK FOR THE STATE RAILWAYS (1912)*

Paragraph 4.—Chill cast-iron wheels are permissible only for freight cars without brakes, and cars with such wheels must only be employed on trains having a maximum speed of 45 km.

SPECIFICATIONS FOR THE FURNISHING OF AXLES FOR TENDERS AND FREIGHT CARS (1909)

Material.—The axles should be manufactured of sound, close-grained Martin first-class steel, manufactured according to the best methods from Swedish pig iron free from flaws or other defects.

The tensile strength of the steel should be at least 45 kg per square millimeter.

Manufacture.—The axles should be rolled entirely straight, round, and smooth, according to the drawings of the State Railways.

The part of the axle which contains the wheel seat is to be rolled with a diameter greater by 8 mm than that of the drawing, and the axle journal shall be polished smooth with emery.

Marking.—The axles shall be marked hot with the name of the manufacturer, name of the material, year of manufacture, number of manufacture, and heat number to which the axle belongs.

(Omitted are paragraphs dealing with the position and size of the letters to be used in the marking of the axles.)

Testing and Inspection.—It is the duty of the contractor to report to the Royal Railway machine-inspection bureau when all or any part of the axles are ready for inspection.

The inspector of the Royal State Railway shall, during the time of manufacture, have free admittance to the shops of the contractor to oversee the manufacture and examination of the materials which are used.

To the inspector shall be given a list of the axles which are ready for inspection, and in this list should be indicated number, material, heat number, carbon content, delivery number, date of order, for the different kinds of axles.

For examination of the quality of the axle material the inspector shall take from each lot furnished one test axle for every 50 axles or fraction thereof, and with the same shall be carried out an impact test with a fall hammer of 1000 kg and with a span between the points of support of the axle of 1.5 m. The height of fall is taken from 3 to 4 m for axles with a diameter at the center of 118 or 135 to 150 mm, respectively, and the axles shall for such blows bend, respectively, 200 or 180 mm without breaking or showing signs of cracks.

From the ends of the axle tested in the impact test shall be taken cold, test specimens, one from each end, with which a tensile test shall be carried out. If the axle passes these two tests, then the lot is accepted. In case this test is not met two new axles are taken out and are tested in the same way and the lot is accepted only if both of these axles pass the prescribed test.

Normal drop testing machines made according to the regulations of the Royal State Railways shall be used in all of these impact tests.

The contractor shall provide without cost the axles used in the tests, and shall also furnish the assistance which is necessary for the carrying out of the test.

(There are here omitted clauses dealing with the painting of axles.)

REGULATIONS FOR THE MANUFACTURE AND DELIVERY OF WHEEL TIRES (1908)

Material.—Wheel tires shall be manufactured of first-quality Martin steel with a tensile strength of at least 65 kg per square millimeter, having at least 14 per cent elongation, on a specimen 200 mm long with a diameter of 20 mm. The material shall be hard and homogeneous and free from blowholes, sponginess, etc.

Method of Manufacture.—Tires shall be well forged under the press or the steam hammer. The profile of the finished tires shall conform exactly to the drawing or sketch of the Royal Railway Administration. The tires shall be exactly round and free from eccentricity. The inner diameter must not deviate by more than 1 mm and the outer diameter by not more than 2 mm from the diameters prescribed in the drawings for each type of tire. The surface should be smooth and free from defects. Each tire shall, after rolling, be annealed and left to cool slowly.

(Paragraphs are here omitted dealing with the marking of the tires.)

Inspection and Testing.—It is the duty of the contractor to report to the Royal Railway machine-inspection bureau when the whole or part of the lot is ready for inspection. The inspector of the State Railway shall during the time of inspection have free admission to the shops of the contractor to oversee the manufacture and to test the material used.

To the inspector shall be given a list of those tires which are ready for testing, and on this list shall be indicated profile number and letter, number, material, heat number, carbon content, inner diameter, manufacture number, and date of ordering.

Before the tests are made the tires should be closely inspected and such be taken out which are found to be defective.

For the testing of the quality of the tire material the inspector shall take from each lot one test tire for every 50 tires or part thereof, and this tire shall be subjected to the impact and the tensile test.

In the impact test the tires shall support without breaking or showing signs of defects a blow of a fall hammer of impact work, 3000 kg m, and shall be capable of bending at least 8 per cent for tires with an inner diameter up to 750 mm, at least

12 per cent for tires with an inner diameter up to 1500 mm, at least 15 per cent for tires with an inner diameter over 1500 mm.

The tires are placed vertically under the fall hammer and the blows strike the tire through a block which corresponds to the profile of the tire. The tire is supported on a similar block. The inspector has the right to have this test carried to destruction with one-third of the test tires, and the breaking may be hastened by notching. The fracture shall show an even and close texture.

From the tire tested in the impact test shall be taken cold a tensile-test specimen which shall be tested in tension. The material must possess the tensile properties mentioned above.

If the tire passes the prescribed tests, the lot is accepted. If not, the inspector has the right to take out for further test 1 tire from every 10 tires, although at least 1 tire from each heat shall be tested again. Only tires of those heats are accepted from which all tires so retested have sustained the drop and tensile test.

Sharp edges on the test tires must be filed away before test.

The normal drop testing machine according to the specifications of the Royal State Railway Administration shall be used for the drop tests. The manufacturer shall without cost provide those tires which the inspector desires for testing, and he shall also without cost supply the labor and materials necessary for the carrying out of the test.

Guarantee.—The contractor must replace those tires which in the course of five years from the month of acceptance of the lot in question, due to defects in the material have to be machined down by an amount of 10 mm greater than that necessary to obtain the required profile.

REGULATIONS IN REGARD TO THE MANUFACTURE OR FORGING OF WHEELS FOR CAR AXLES (1908)

Dimensions of wheels should be exactly those that the Royal State Railways indicate.

The wheel centers must be made entirely of (smidt järn) wrought iron and should be completely forged together both in the hub and the tire without burning at the spokes. The hub shall be turned on the sides, and the circumference shall be turned smooth to the diameter that is necessary. The tire is machined on the side and also on the outer circumference, and the diameter of the latter shall agree with the dimension given in the sketch, and unevenness must not show after turning and boring. Each wheel center must be manufactured so carefully that the center of gravity lies in the geometrical axis of the wheel, and examination in this respect shall take place on each wheel before forcing wheels onto the axles. This examination takes place by supporting the wheel upon a special axle which must rotate upon plane or conical supports; the difference in weight between the wheel centers which are selected for one and the same axle must not exceed 1 kg.

The wheels should be pressed onto the axles with a hydraulic press with a pressure of —— kg. Both of the wheels should be pressed on at the same time.

The wheel tires shall be of first quality Martin steel and manufactured in accordance with the regulations regarding the manufacture and delivery of wheel tires, and in case they are not manufactured by the contractor furnishing the axles the manufacturer of the wheel tires must be responsible for the delivery of the axles directly to the Royal State Railways. In case they can not be obtained from a domestic manufacturer they must only be ordered from such foreign manufacturers as are approved by the Royal State Railway Administration.

The tires should be turned completely cylindrical at the inner circumference and with a shrinkage measurement of 0.001 and shall be fastened to the wheels by means of spring rings.

The difference in carbon content of the wheel tires for the same axle must not exceed 0.05 per cent.

(From here on the text, which deals with the marking and balancing of the wheel sets, is not completely reproduced.)

The turning of the tires shall not take place until after the wheels have been forced onto the axles. After the wheels have been pressed onto the axle it shall be placed with the journals upon two horizontal supports and must then be in equilibrium without tendency to roll in either direction.

The center of the wheels after the manufacture shall be stamped with the name of the manufacturer and the material and also the year of manufacture in large and plain letters.

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DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 62

MODERN PRACTICE IN THE CONSTRUCTION AND MAINTENANCE OF RAIL JOINTS AND BONDS IN ELECTRIC RAILWAYS

BY

E. R. SHEPARD, Associate Electrical Engineer

Bureau of Standards

SECOND EDITION

INCLUDING AN APPENDIX DESCRIBING RECENT DEVELOPMENTS AND IMPROVEMENTS

ISSUED FEBRUARY 9, 1920

WASHINGTON
GOVERNMENT PRINTING OFFICE
1920

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I. INTRODUCTION

While studying electrolysis and electrolysis mitigation during the past five years the subject of rail bonding and track conductivity has been brought forcibly to our attention by observations on railways where electrolysis surveys have been made, by a vast amount of discussion of the subject in the technical press, and by conversation and correspondence with railway engineers. This keen interest in track bonding originated largely through the necessity of mitigating electrolysis, and while electrolysis continues to be the greatest stimulus for bond maintenance, it is as a rule justifiable solely from the standpoint of good operation, and is an absolute necessity for the successful operation of block signals.

In view of the great variety of bonds and bonding practices in use at the present time, and the large percentage of failures after 25 years of experimentation on the part of the operating and manufacturing companies, and after repeated calls for information and advice on the subject from railway engineers, the Bureau of Standards deemed it advisable to institute a thorough investigation regarding the present status of bonding and joint maintenance with the idea of disseminating information that will aid the companies in selecting bonds and joints, and in methods of applying and installing them, as well as of calling attention to the importance of good track conductivity and its true relation to electrolysis and its effect upon electric railway operation.

Owing to the peculiar nature of the services that rail bonds and joints are called upon to perform and the great variety of conditions under which they operate, it was recognized that information obtained under service conditions over a period of years would be far more reliable and satisfactory than any laboratory or short-time tests that could be conducted. Many laboratory tests have been made by the manufacturers on the durability and resistance of different types of bonds and joints, and while such tests are valuable in determining the characteristics of a bond, they can not be taken as a criterion for the performance of the average bond under service conditions.

The personal element which enters so largely into the installation of bonds, and the variety of conditions under which they operate made it necessary to obtain information from a large number of sources and to base conclusions only on testimony submitted by a great many witnesses. Accordingly, data were collected through a large number of circular letters and other correspondence, by personal visits to some 50 operating companies, as well as to practically all of the manufacturers of bonds and rail joints.

Owing to the rapid growth of the electric railways, the numerous changes in the standards of construction, the improvements in materials and methods, the franchise and street-paving requirements, the changes in organization and administration, and the transient nature of the engineering staffs, it was found difficult to get definite and consistent information regarding the operation of any type of bond or joint over a period of years. Many of the companies consulted had kept only meager, if any, records of their bonding, and their replies, of necessity, were based largely on opinions. Few engineers were able to give with any degree of certainty the average life of a given type of bond. Either the bond had not been in service long enough to warrant a statement or else no definite records were available.

New inventions and recent improvements in the manufacture and installation of bonds and joints, as well as changes in the types and composition of rails, all contribute to an unsettled condition at the present time, which means that a great number of bonds and joints now in service are in the experimental stage.

While the larger operating companies have the engineers and resources with which to meet the bonding problem with more or less success, the smaller companies must depend in a large measure upon these and other external sources for their standards. This has not always been to their advantage, as many practices employed by the larger companies are not applicable to the smaller systems. Local conditions or city restrictions frequently limit the types of bonds that might be employed. The result is that many companies have been confused by the apparent inconsistencies in adopted standards, not realizing that each has been worked out to meet peculiar conditions.

A great many railways have settled on certain bonding standards and are apparently satisfied with the results they are obtaining, not that they believe they have the one and only best standard, but they are tired of experimenting and are willing to let well enough alone. Others, and perhaps the majority of the companies, are not satisfied with their present practices, and are looking for something better suited to their requirements.

In view of the conditions described above it can not be expected that this investigation will clear up a most vexatious question, nor in any way purport to be the last word on the subject. The Bureau of Standards hopes, however, in tabulating and analyzing the data which have been collected, to discern and interpret the present tendencies and to reconcile some apparent inconsistencies and differences of opinion. Its aim will have been fulfilled if it succeeds in laying before the electric railway companies, and particularly the smaller companies with limited resources, information which will be a guide to the selection of bonds and joints; and, what is of still more importance, in pointing out the best methods of application and maintenance and in emphasizing the necessity of adhering to them.

II. HISTORICAL AND GENERAL DISCUSSION OF BONDS AND JOINTS

Although early attempts were made to operate cars on unbonded tracks, relying upon the joint plates and the earth for conductance, it soon became evident that a metallic bond was necessary both from the standpoint of good operation and for the prevention of

stray currents, which were early found to have a corrosive action on underground structures.

Numerous types of iron and copper bonds came into use, many of which are now obsolete, and a description of which would be of no particular value to this paper. Those types which have found general use will be discussed with reference to their features of installation and the conditions under which they operate. No academic classification of bonds will be attempted.

The great number of different types of bonds which have appeared in the past years is largely the result of attempts to better meet the exacting requirements which this piece of apparatus is called upon to fulfill.

While these requirements and the different types of bonds which they have called forth are familiar to the majority of railway engineers, the most important of them are here briefly described by way of introduction to a later part of the paper, where, in connection with testimony submitted by the operating and maufacturing companies, a more detailed account of the manner in which the various types of bonds are meeting the requirements of service will be discussed.

1. BOND REQUIREMENTS

(*a*) Intimate and Permanent Contact With Rail Under Service Conditions.—Perhaps the first and most important requirement of a rail bond is that it make good electrical contact with the rail and that this contact remain good over a period of years while subjected to the mechanical vibrations of traffic, changes of temperature, the action of soil and moisture, and to the mechanical injuries from workmen and vehicles. In general, three methods of making contact with the rail have been employed, viz, soldering, mechanical, and brazing or welding. Combinations of these have also been used. Each method will be treated under the types of bonds employing it.

(*b*) Durability.—The durability of the bond itself depends, first, upon its ability to withstand the bending and vibration incident to expansion and contraction of rails and the deflection of the rail joint under traffic, and, second, upon its ability to withstand electrolytic and soil corrosion.

The first action is by far the more severe and has resulted in the failure of more bonds than has any other one cause. Loose rail joints are the chief cause of such failures, and the problem of bonding is therefore intimately related to the problem of joint maintenance.

The second cause of deterioration, that of corrosion, is rarely important, although in extreme cases it may be serious. Iron bonds buried in the earth and copper bonds in soils of certain character, or on tracks from which large leakage currents are escaping, have been known to corrode at a very rapid rate.

(*c*) Ease of Installation Under Service Conditions.—For the greatest practical value a bond should be of such a nature that it can be safely and quickly installed under service conditions; that is, while traffic is being maintained over the tracks. For new work this may not be required, but for repair and replacement work its importance is obvious. While bonds are frequently installed at night and traffic is sometimes diverted for the purpose of installing bonds, such practices are decidedly objectionable. Moreover, it is possible for bonding apparatus to offer a hazard to the safe operation of cars. Though not of prime importance, these features can not be neglected in the selection of a bond.

(*d*) Low Resistance.—Under ordinary conditions the resistance of a bond within moderate limits is subordinate to its other qualities. Obviously, it must have a cross section sufficiently large to carry the track current without undue heating, but as a rule its length will be determined by other considerations. Where the resistance of bonded joints is limited by ordinance, or where for special reasons a high conductance is required, this feature may be a determining factor in the selection of a bond.

(*e*) Proof Against Theft.—In many localities the theft of rail bonds has become so prevalent and the losses from this source so heavy that the resources of the railways have been seriously taxed to cope with the problem. To-day no bonding of suburban track can be undertaken without due consideration of this feature, and either bonds designed to overcome this trouble must be selected or some other preventive means employed.

(*f*) Reasonable Cost.—While the consideration of cost can not be neglected in the selection of apparatus and material, its promi-

nence may in some instances be entirely overestimated. It is not always apparent that ultimate economy may result from a high first cost, and with the difficulty in securing approval of estimates for bonding from those who do not always appreciate the importance and necessity of this work the more expensive bond is likely to be seriously handicapped in its bid for consideration. Although the general manager who wants to know why bonding is necessary when the cars are operating under existing conditions is rather the exception, there are many who place bonding at the end of the budget, so that the engineer is sometimes forced to employ material and methods for the sake of economy which are against his better judgment. It is quite evident, therefore, that the first cost of a bond, which of course includes the cost of installation, although having little relation to its ultimate economy, in many cases might be the determining feature in its selection.

2. TYPES OF BONDS

(*a*) OLD TYPES.—Early bonding was accomplished by riveting or bolting solid iron or copper wires to the web or base of the rails. This general practice was not long employed, as it was soon found that such contacts rapidly deteriorated from corrosion. Practically none of these bonds are in use at the present time and the types can be considered as obsolete.

Channel-pin bonding, as shown in Fig. 1, consists in driving a grooved plug into a hole in the rail with a round wire fitted into the groove in the plug, found early favor with the railway companies owing to its low cost and ease of installation. It is still to be found in service on old tracks and has a very limited sale at the present time for temporary use in mines and for other special purposes. These special conditions, however, are being met by modern and more satisfactory types, thus leaving this bond with a very limited field.

Originally steel plugs and solid copper wires were used, but the practice has been varied by the use of copper instead of steel plugs and in other cases by copper-plated or tinned plugs. Sometimes the plug entirely encircles the wire in the form of a sleeve.

Although there are cases on record where this type of bond maintained good electrical contact with the rail for many years

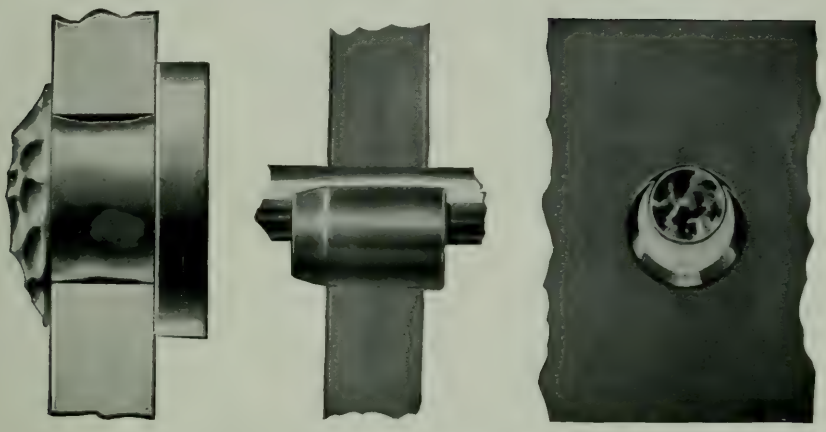

FIG. 1.—*Riveted and channel pin bonds*

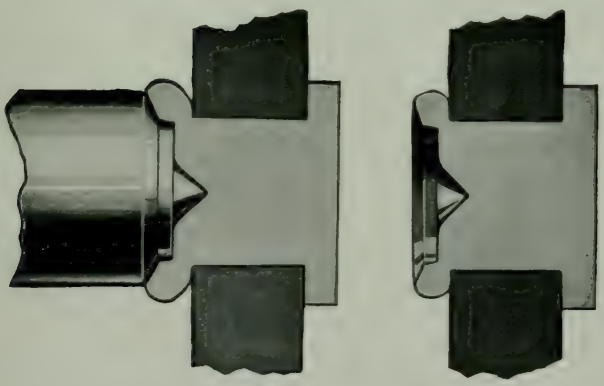

FIG. 2.—*Compressed terminal type*

under service conditions, the results obtained in general were poor. Moisture invariably found its way between the plug and the rail, or between the wire and the plug, thereby causing corrosion and an increasing contact resistance.

Channel pins and iron bonds still find a limited application on suburban tracks where the theft of copper bonds excludes that type, and where the rail and joint plates are of such dimensions as not to permit the use of concealed bonds. Under such conditions they are admittedly a makeshift and are employed only as a last resort and in the absence of any satisfactory method of bonding.

(*b*) Soldered Bonds.—With the failure of the riveted, bolted, and channel-pin bonds the necessity of a bond making a more perfect and permanent contact with the rail became apparent. The soldered contact early came into use to meet this demand and found universal adoption. With the exception of the most modern installations practically every electric railway company in the country has employed the soldered bond in one form or another. Its low cost and ease of application were in its favor and appealed to the operating companies. It can be applied to either the head, web, or base of the rail, requires no drilling, and can be installed without interruption to traffic.

The one serious objection to this type of bond is the difficulty in securing a permanent and low-resistance contact. The failures of soldered contacts are due to inherent defects in the method as well as to poor workmanship in installation. Copper has a coefficient of expansion nearly twice that of steel and somewhat less than lead-tin solder. It is evident, therefore, that with the diurnal temperature variations that steel rails undergo the soft film of solder connecting the two different metals is subjected to continual alternate strains which, in the presence of moisture and under the vibrations due to traffic, will eventually result in failure.

There are few mechanical processes in which the personal element enters so largely as in the application of bonds, and this is particularly true with respect to the soldered bond. As a rule, skilled mechanics are not employed for this work and the ordinary track laborer is slow in mastering the apparently simple feat of soldering a rail bond. In fact, he is a rare workman if he ever does learn the intricacies of this process and conscientiously ap-

plies his knowledge at all times. The soldered contact between bond and rail frequently corrodes without exhibiting any external signs of such deterioration. The bond might even resist a moderate blow from a hammer and still show a very high resistance when tested with a bond tester. Inspection therefore is not a reliable means of determining the condition of soldered bonds.

Another inherent defect of the soldered bond is the comparative ease with which it can be removed from the rail by copper thieves. A short bar is all that is necessary to remove these bonds from the head of a rail, and enormous losses of this type have occurred where the labor and time necessary to remove other types would have saved them.

While there are some engineers who still retain faith in the soldered bond, and a few companies employing well-trained and careful workmen continue to install them, their inability in general to meet the requirements of service have led to their abandonment by the majority of operating companies.

(*c*) Compressed Terminal and Pin-Terminal Bonds.—Compressed terminal bonds, shown in Figs. 2 and 3, are those having cylindrical terminals which are compressed with a screw or hydraulic compressor into holes drilled or punched in the web or base of the rails. They are referred to by the various manufacturers as compressed terminal, solid terminal, and compressed stud terminal bonds. Pin-terminal bonds are those having tubular terminals which are expanded into holes drilled or punched in the web or base of the rail by driving a steel pin into the hole in the terminal. They are referred to by the various manufacturers as pin-terminal, tubular-terminal, and pin-driven bonds. They will be referred to in this paper simply as pin-terminal bonds. The term "stud terminal" will be used to include both of the above types.

These bonds are made either in the solid, stranded, or ribbon type, and are designed either for concealed or exposed application. Although a great diversity of opinion exists regarding the merits of these bonds, they have found wide application and for more than 15 years have remained the standards for numerous companies. Owing to their wide use at the present time and in view of the general interest manifested by the companies in them,

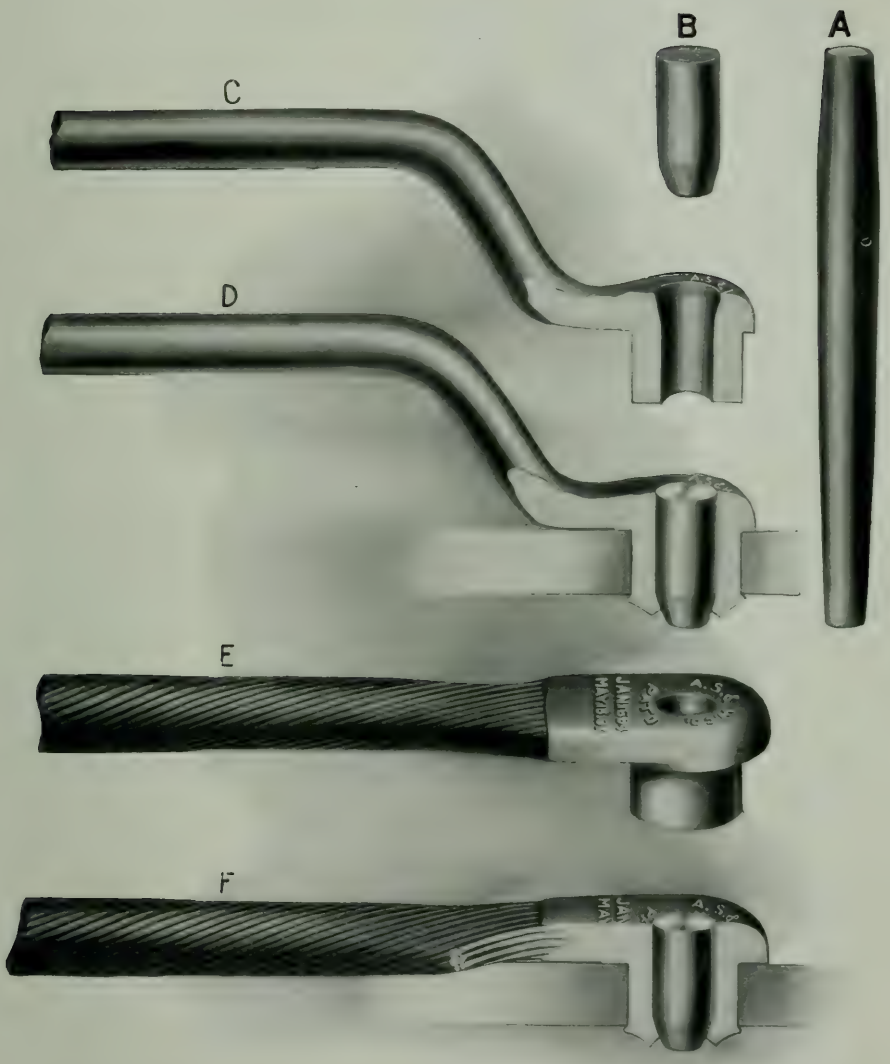

FIG. 3.—*Pin-terminal bonds*

a somewhat detailed account of their properties will here be in order.

Some difficulty was at first experienced by the manufacturers in securing a perfect union between the terminal and the strands or ribbons of these bonds. The successful welding of copper requires certain precautions in the exclusion of oxygen, and until improvements were made in their furnaces and methods the bond manufacturers found difficulty in turning out bonds with properly welded terminals. This defect has been entirely overcome, so that it is now possible to obtain bonds which are perfect in this respect. To overcome this trouble some manufacturers have forged the terminals from the wire strand of the bond itself.

Another improvement in the construction of stud-terminal bonds which has come into use only in recent years is that of machining the terminals. Before this practice was employed the inequalities in the stud made it difficult to obtain a perfect contact over the entire surface of the terminal. This gave a chance for the entrance of moisture between the copper and steel, with resulting corrosion and rapid deterioration. A film of moisture on the contact acts as an electrolyte, and with the passage of electric current rapid corrosion took place. A number of manufacturers now machine all bond terminals, while others do so only when specifications require it. The additional expense is small and most companies are willing to meet it for the increased life of the bond. Other improvements in the nature of annealing or softening the copper have added to the value of stud-terminal bonds by permitting a better flow of copper and consequently a better union with the steel.

Failure of the bond itself, due to the crystallizing and breaking of the wires and ribbons, has been largely overcome by increasing its length and by using a size of wires which experience has shown will withstand the maximum amount of mechanical vibration. Attention has also been given to the matter of forming bonds to conform to the joint plate and rail sections.

While the manufacturers have been active in their efforts to reduce the failures of the stud-terminal bonds, by introducing improvements and refinements in their methods of construction, the utility of these, as well as all other types of bonds, has been

greatly increased by improved methods in their installation. The importance of great care in the installation of stud-terminal bonds was, at first, not always appreciated by either the engineer or the workman. The many precautions and refinements now known to be imperative for best results were not known in the early days of electric railway engineering. Electric roads were springing up like mushrooms in every city. In many cases they were built by contract at so much per mile and concealed bonds received scanty attention. Indeed, cases are on record where bonds have been removed from such roads after a period of years and were found not to have been compressed or expanded at all but simply driven in the holes drilled to receive them and covered up by the joint plates. Bonds poorly installed frequently gave good service for a short time; sometimes for a few years. Even if they did not, the joint plates and the earth roadbeds frequently sufficed to return the current to the generators, and until water and gas leaks began to develop, or until the necessity for better service called attention to the poor return circuit, the bonds often received no consideration. It is little wonder, therefore, that years were required to establish the facts regarding the proper methods of bonding. The high percentages of failures that have been recorded in the past were apparently, therefore, on bonds which were manufactured and installed under conditions far different from those existing at the present time or even in recent years, and they can not be considered as an index to the performance of modern bonds installed under more favorable conditions.

Some of the features of installation which have contributed to the failure of stud-terminal bonds are here recounted: (1) The drilling of too large holes, thus requiring too great compression or expansion to make good contact. Holes are now usually drilled having the same diameter as that of the bond terminals. (2) Rough or irregular holes caused by dull or imperfectly ground drills. (3) Installing bonds in old, corroded, or wet holes. Bonds are now installed in only freshly drilled holes, perfectly clean and dry. (4) The use of oil in drilling. A film of oil between bond terminal and steel impairs the contact. Holes are now, as a rule, drilled dry. (5) Failure to clean web of rail around hole. Rust or scale on the web of the rail with which the face and button of

the bond comes in contact is likely to permit the admission of moisture to the contact. The best modern practice requires the grinding of the rail adjacent to the hole. (6) Incomplete compression or expansion of terminals. (7) Old or wrongly shaped compressor face. (8) Carelessness in driving expanding mandrel or pin. (9) Failure to clean bond terminal before installation.

As with the soldered type the personal element enters largely into the installation of stud-terminal bonds, evidence of which is given by reference to the numerous details recounted above.

The foregoing is considered a sufficient introduction to the discussion and comparison of the pin terminal and compressed-terminal bond which is to follow in connection with the reports of the operating companies.

(*d*) Brazed or Welded Bonds.—This type includes all bonds in which either the copper terminal of the bond is welded directly to the rail or in which a third metal, such as brass or some other hard solder, is used to effect the union. Heat may be applied by any means, the most common being the passage of an electric current through the members being united, the electric arc, and the oxy-acetylene flame. The pouring of molten copper into a mold around the bond terminal has also been employed. The following definitions are in common use and will be adhered to in this paper.

Electric Weld.—Though commonly called a brazing process this term is used by the Electric Railway Improvement Co. in reference to the operation in which current passing through carbon electrodes in contact with the bond terminal generates the welding heat. It will here be employed in that connection.

Arc Weld.—A weld or brazing process affected by heat generated by an electric arc.

Oxy-Acetylene Weld.—A weld or brazing process affected by the use of the oxy-acetylene flame.

Copper Weld.—A weld or brazing process affected by pouring molten copper into a mold surrounding the bond terminal.

Up to the present time the use of the welded or brazed bonds has been confined almost entirely to that of the electric-weld type.

These bonds are more modern than the soldered and mechanically applied types described above, and their manufacture and

use has been greatly stimulated by the high percentage of failures attributed to the imperfect contacts of the latter-named types. A greater stimulus, however, was the growing need for a short exposed bond which could be applied to the head of the rail without removing the joint plates and which would make such tenacious contact as to discourage the attempts of copper thieves to remove it. The need for such a bond was so strong and the brazed or welded bond met the requirements so admirably that it at once sprang into extensive use, particularly on open track, even before time had demonstrated its lasting qualities. To guard against theft on suburban tracks and also to reduce its cost the bond was of necessity made comparatively short. This feature led to a rather high rate of failure from the breakage of the wires or ribbons, particularly on roads having poorly maintained rail joints. Imperfect methods of application and carelessness in installation also contributed to the failures of this type.

Like the stud-terminal bonds, therefore, the electric-weld bond had to go through an experimental stage. Improvements in construction, adoption of new types, as well as education of the railways in the methods of installation have progressed until to-day most of the early defects have been overcome and the bond is supplying a wide and growing demand.

The chief objections to the electric-weld bond are, first, as usually applied, their installation requires the purchase of rather an expensive bonding car, and, second, the bonding car is inconvenient to operate on tracks over which traffic is being maintained. The first objection is a serious one for small roads having limited means, and the second objection applies to all tracks on which the headway is of the order of 30 minutes or less. It is necessary to derail the bonding car to let regular trains pass, and this is obviously impracticable under a short headway. These objections are not pertinent to other types of welded bonds, and for this reason they are now making a strong bid for recognition.

Figs. 4 and 5 show two types of electric-weld bonds in common use. The ET type, which is the newer of the two, was recently designed to overcome defects in the EA type The manner in which the conductors of the EA type met and joined the bond terminal permitted of considerable bending and vibration at that

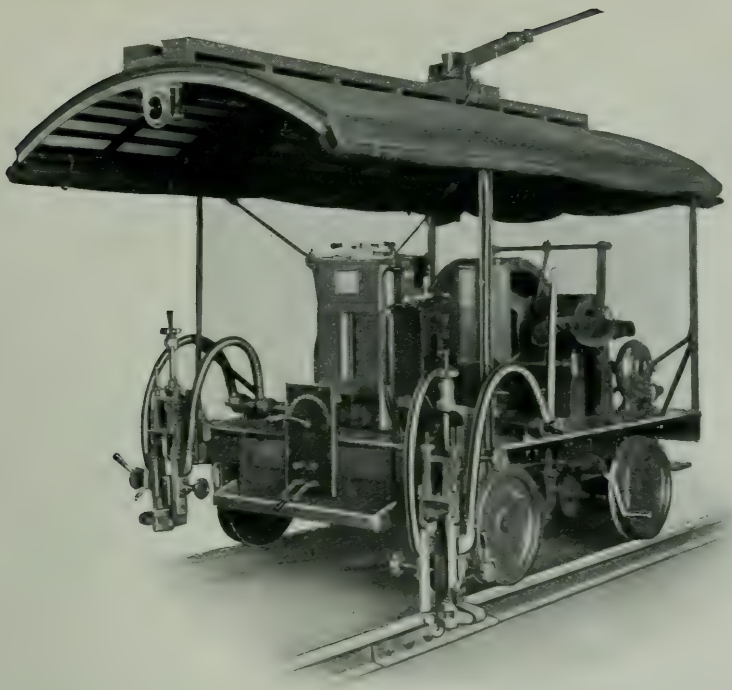

FIG. 6.—*Car for applying electric-weld bonds*

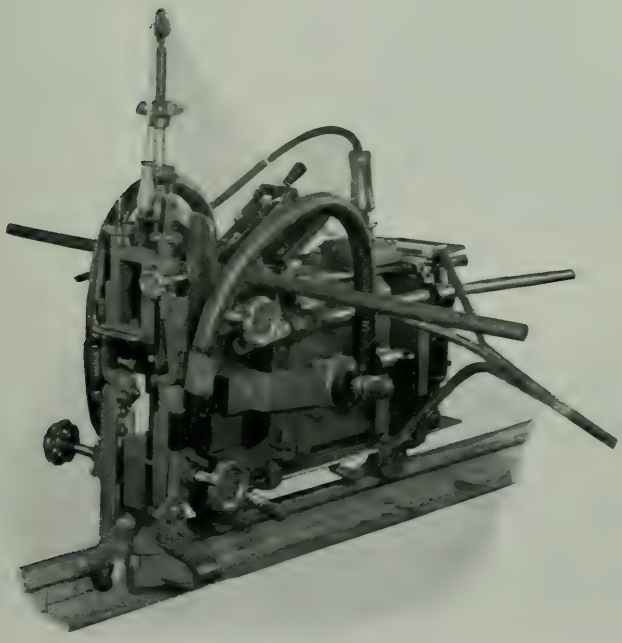

FIG. 6a.—*Portable welding transformer*

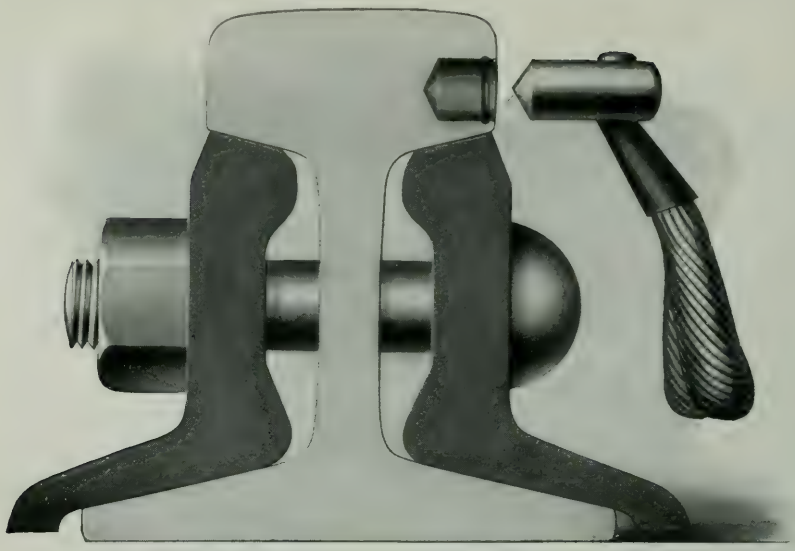

FIG. 7.—*Twin terminal bond*

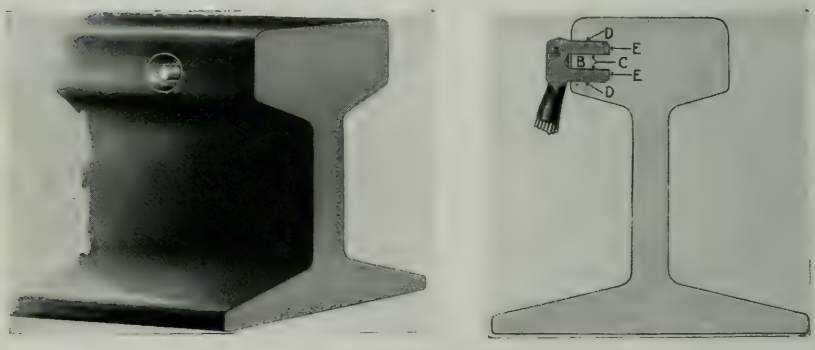

FIG. 8.—*Tubular terminal bond*

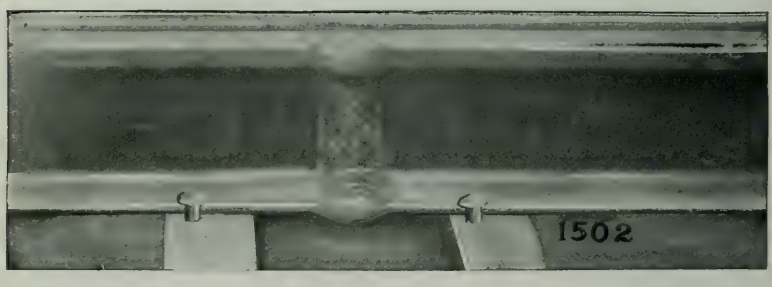

FIG. 9.—*Thermite weld*

point on poorly maintained joints and resulted in considerable crystallization and breaking of the ribbons. In the ET design the flexure is distributed throughout the entire length of the bond, thereby greatly reducing the failures from this source.

Where alternating current is available a portable outfit, shown in Fig. 6*a*, is employed. It is less expensive and more convenient to use than the bonding car.

(*e*) MECHANICALLY APPLIED HEAD BONDS.—Under this heading will be included the twin-terminal bond shown in Fig. 7 and the

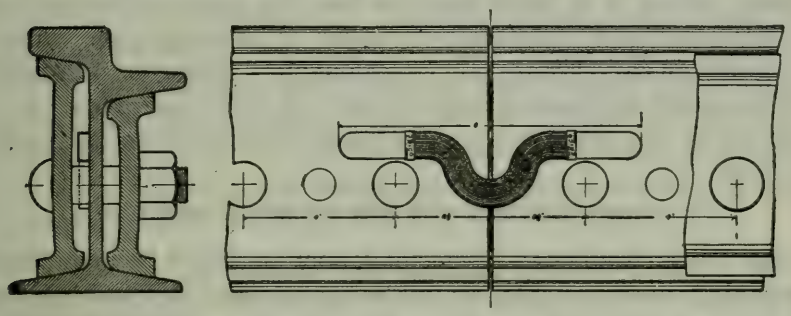

FIG. 4.—*Type EA electric-weld bond*

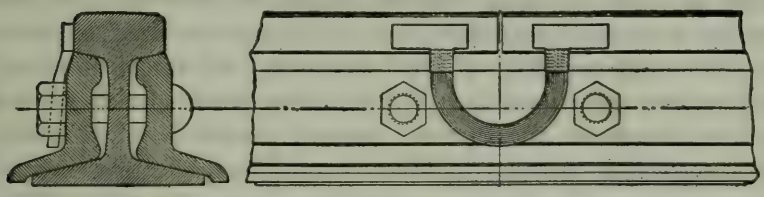

FIG. 5.—*Type ET electric-weld bond*

tubular-terminal bond shown in Fig. 8, both of which are short bonds applied to the head of the rail and used principally on suburban open track. The former employs two studs on each terminal about 1¼ inches apart which are driven into holes drilled in the head of the rail and upset, while the terminal of the latter type is tubular in form and is driven into an annular shaped hole milled in the head of the rail. Both types are short, comparatively inexpensive to install, make fairly good contact with the rail, can easily be inspected, and are relatively hard to steal. They may still be said to be in the experimental stage, however, and a

few more years will be required to demonstrate their ultimate utility.

(*f*) TUBULAR BONDS.—Recently a tubular copper bond has been placed on the market which is designed to join the web of the rail with the joint plates by expanding it into holes drilled through the three members at right angles to the length of the rail. It is about 4 inches in length and 1¼ inches in external diameter. At least two are required for each joint and more may be used This bond has not been in service long enough to demonstrate its utility, but as it is called upon to bear the joint strains incident to expansion and contraction its ability to maintain good contact with the rail and plates is very questionable. However, if installed on improved mechanical joints where bolt holes are reamed for a driving fit, it is possible that this bond would prove entirely satisfactory.

3. CROSS BONDING AND SPECIAL-WORK BONDING

(*a*) CROSS BONDING.—If all joint bonding could be maintained in perfect condition there would be no occasion for cross bonding of the two rails of a single track, although on double track the utility of cross bonding between tracks is obvious. As perfect bonding is an ideal condition, practically never realized, experience has shown the necessity of cross bonding both single and double track at frequent intervals. The function of cross bonds on single track is to shunt the current around poorly bonded or high-resistance joints, thereby tending to equalize the return current in the two rails. On double tracks they not only act as shunts around high-resistance joints but also act as equalizers between tracks which may not always be uniformly loaded. In the absence of cross bonds serious unbalancing of the return current is likely to result on poorly bonded tracks, which not only makes for excessive power loss and poor operation but introduces bad electrolysis conditions. Under extreme conditions it may also actually prove a life hazard to horses and pedestrians. A case is on record of a horse being thrown to the ground by bridging the two rails of a track. Actual test showed a difference of potential between the rails of 80 volts. The question of the intervals at which cross bonds should be installed is a pertinent one on which further discussion is to follow.

(*b*) SPECIAL-WORK BONDING.—The problem of bonding special work offers some features not present on straight track. The joints are difficult to maintain, pounding due to traffic is excessive, frequently hard steel is used to which certain types of bonds can not well be applied, the sharp angles in frogs exclude the use of certain bonding tools, and the replacement of steel is more frequent than on straight tracks. Owing to these complications it has been found difficult to maintain good bonding through special work, and as a result it has become standard practice to bond around all such sections with heavy conductors. These are relied upon to carry the main current, and light bonding is usually installed to take care of the current originating in the section thus shunted out. Cables employed for this purpose can not be left exposed in unguarded regions as they offer particular temptation to copper thieves. Even when buried in the earth they are frequently dug up and removed by junk vendors.

4. WELDED AND SPECIAL JOINTS

With the advent of heavy electric traffic in paved city streets the bond and joint problem became acute. Both were found difficult to maintain and the repair of either entailed considerable expense in removing and replacing pavements. The rail joint was recognized as a weak link and the limiting factor in the life of their tracks by the operators; and when it was proposed to obliterate it by welding the joint, and was demonstrated to be a practical possibility, the idea was eagerly incorporated by many companies. Although the welded joint, like the rail bond, has had a somewhat checkered history and has met with many reverses and failures, it has grown in use until at the present time it is a standard of construction in some form or another in nearly every large city in the United States. The several types of welded and special joints which are now in service will be briefly described here, leaving a fuller discussion to the operating companies whose testimony is to follow later.

(*a*) CAST WELD.—This term is used in reference to an early type of weld, sometimes called the Falk joint, produced by pouring molten cast iron into a mold around the ends of the abutting rails, the latter having been cleaned by a sand blast or some other means.

In many cases it was not a weld at all owing to the difficulty in preheating the cast iron sufficiently to melt the steel of the rails. It was a good mechanical joint, however, and frequently served admirably the functions of both bond and joint plates. The many failures that occurred in this and other types of welds have been attributed to numerous causes. Whether the heating of the rail was sufficient to change its properties, and thereby result in excessive wear and breaks, has occasioned a great deal of discussion and is still a mooted question. Expansion and contraction has undoubtedly been responsible for failures in some cases, particularly where rails were welded in hot weather or laid in pavements having poor binding qualities. The cast weld is still doing duty in a number of localities, but in competition with other types, which are accomplishing the desired results in a more satisfactory manner, its installation has been practically abandoned.

(*b*) THERMITE-WELDED JOINT.—This is essentially a cast weld, but as the temperature attained by the reaction of aluminum and iron oxide is far in excess of that produced in the ordinary cast weld, the ends of the steel rails are melted down and an obliteration of the joint actually results. This method found early and wide application on experimental scales owing to the comparatively simple manner of obtaining a complete weld of the joint, but later it suffered a setback owing to the large number of joints which were found to cup after bearing heavy traffic for some time. In order to properly make the weld it was necessary to leave a space of about three-quarters of an inch between the rail ends and fill in with the molten metal. As it was practically impossible to duplicate the physical properties of the rail a soft spot was left which eventually gave rise to cupping. Recent improvements have eliminated this defect, however, and the joint is again finding favor with the railways. It requires much less metal than the old cast weld, and has a high conductance. It is better adapted for new than for repair work, as the process is difficult to carry out under traffic conditions. A completed weld is illustrated in Fig. 9.

Thermite welds have also been used in connection with mechanical joints. A shoe of thermite steel is poured around the base of a bolted or riveted rail joint, thereby welding the base of the

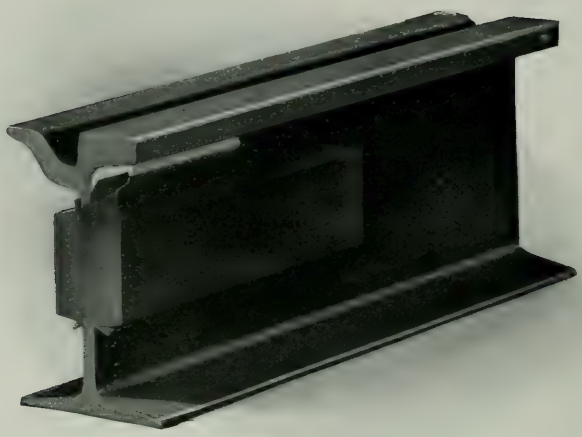

FIG. 10.—*Electrically welded joint with head support*

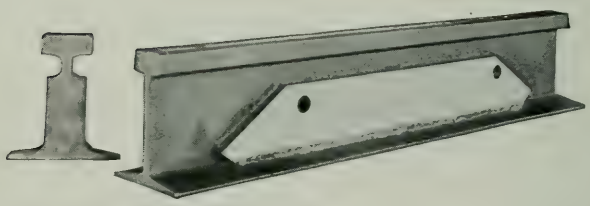

FIG. 11.—*Arc welded joint*

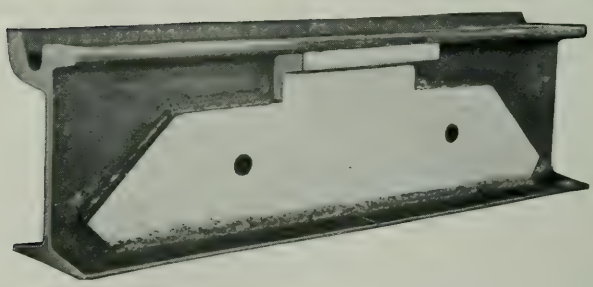

FIG. 12.—*Arc welded joint with head support*

rail but in no wise changing the properties of the head or running part. The joint needs no other bond and is mechanically good. It has met with marked success in Baltimore and Cleveland, where it is known as the "Clark joint."

(*c*) ELECTRICALLY-WELDED JOINT.—The electrically-welded joint was introduced over 15 years ago and has found wider application than any of the other modern types. It consists of heavy bars or plates from 2 to 3 feet in length spot welded to the web of the rail by the use of an electric current. The process requires a heavy and expensive plant and is usually carried out by contract on a comparatively large scale. For this reason it is not well suited to installations on small systems. It is well adapted to the reclaiming of old track as well as for new work and has been applied on open T-rail construction where expansion joints are installed at intervals to provide for expansion and contraction. Fig. 10 shows a section through the center of an electrically-welded joint with head supports.

Failures of this type of weld have in general been confined to fracturing of the rail at the end of the welded bar and are no doubt the result of strains introduced into the web of the rail from the localized heating. Such breaks have been more prevalent in old than in new rails. On new work with rails having no bolt holes the failures have been reduced to a minimum, which is not considered serious.

(*d*) ARC-WELDED JOINT.—This term will be employed in reference to joints in which the plates have been welded to the rail by means of an electric arc. The method is comparatively modern and is just emerging from the experimental stage. The features which appeal to the operating companies are ease and simplicity of application, low cost, and high conductance. In the most recent types the rails are not heated to an injurious degree.

This method of welding has also been applied to the welding of rails to steel ties and also to the welding of bolted and riveted joint plates to the base of the rail. This latter process provides for a joint of high conductance, strengthens it mechanically, and eliminates any possible danger from heating the web and head of rails. The recent adoption of this process for welding joint plates by numerous companies after a trial installation is strong evi-

dence of its utility for this purpose. Two improved types of welded joints are shown in Figs. 11 and 12.

(*e*) THE NICHOLS COMPOSITE JOINT.—This joint consists of two plates which fit the web of the rail and are riveted snugly to it but which do not come in contact with the fishing surfaces. The spaces thus left around the head and foot of the rail are filled with molten zinc, which expands upon solidifying and enters into all of the irregularities of the rail surface. If the rail and plates are properly cleaned before pouring the zinc, a good electrical contact is obtained and a joint of high conductance is the result. The process is rather expensive, and is warranted, therefore, only on lines bearing heavy traffic. The fact that it has been a standard of construction in the city of Philadelphia for a number of years is an indication of its practicability.

(*f*) MECHANICAL JOINTS.—In recent years a number of companies have gone to some pains and expense in the construction of bolted and riveted joints designed to eliminate the effects of expansion and contraction, which in the ordinary bolted joint often results in looseness and ultimate failure. Where bolts are used, the holes are drilled undersized and carefully reamed out to give a driving fit. Machine bolts with square heads are used and an accurate shop fit is obtained in the field. Rivets are sometimes substituted for bolts. In some cases the plates are drilled short and heated to make the holes meet. When they shrink, the ends of the rails are drawn together with a great force and trouble from cupping is thereby largely eliminated. Such mechanical joints as here described, when carefully bonded, possess the best features of the welded joint and are free from some of the latter's defects. It is obvious that they can not be used in other than paved streets unless some provision for expansion and contraction is made.

III. COMPILATION OF INFORMATION SUBMITTED BY OPERATING COMPANIES

1. QUESTIONS SUBMITTED AND NATURE OF REPLIES

Before asking for information or opinions from any of the operating companies, a thorough study of the bond and rail joint problem was made by a careful reference to all trade literature

available, by correspondence with manufacturers, and review of the technical literature of the subject.

After obtaining a fair knowledge of the problems involved and the present practices employed, a circular letter and list of questions were prepared for distribution among the operating companies. The letter called attention to the lack of uniformity among the operating companies in their bonding practices and the need for cooperation in an effort to better solve the difficulties connected with the problem. It asked for a free discussion of the subject and for individual opinions rather than a reply confined to the answering of definite questions. This letter, together with a copy of the questions, was mailed to a list of 130 operating companies selected from every State of the Union, made up for the most part from the larger companies, although a number of companies operating railways in cities of from 15 000 to 40 000 population were included.

Following is a list of the questions submitted:

RAIL BONDS

1. What types and sizes of rail bonds have you used? State whether soldered, brazed, welded, compressed, or expanded terminal bonds; whether solid, stranded, or ribbon; whether concealed or exposed; to what part of the rail attached; number and length of bonds per joint.

2. On what type of construction has each type of bond been used? Give weight of rail, length of rail, type of rail, type of splice bars, type of roadbed, kind of pavement adjacent to rails, character of traffic.

3. About how many of each type and size of bond have you in operation at the present time?

4. Do you inspect your bonds regularly? If so, how, and how frequently?

5. Do you have a definite criterion for determining when a bond requires replacing? If so, what is it?

6. About what is the average life of each type of bond? Give the percentage of failure for each year after installation.

7. At what intervals do you cross bond the two rails of each single track; also the two tracks on double-track construction?

8. On what basis do you determine the size of cross bonds to be used?

9. Do you bond around all special work?

10. What type of bonds do you use for cross bonding and special-work bonding?

11. To what extent have you been troubled with theft of different types of bonds?

12. What grade of labor do you employ for the installation of different types of bonds, skilled or unskilled?

13. What special tools and machinery do you employ in the installation of different types of new bonds; also, in the repair of bonds?

14. Do you use a lubricant in drilling for compressed or expanded terminal bonds?

15. Are your drills machine or hand ground?

16. What is the complete cost of installing each type of new bond when installed in large numbers; also, of renewing a bond? State in detail how costs are computed. (The total cost of installing a bond should include the cost of the bond, the cost of the tools, the interest and depreciation on the tools and machinery, supplies, electric energy if used, labor, and paving repairs.)

17. What is the most prevalent cause of failure of each type of bond?

18. What is the average resistance in terms of rail length, or in ohms, of each type of bonded joint when new and when old?

WELDED AND OTHER TYPES OF RAIL JOINTS

1. What types of rail joints, and how many of each type, have you in operation at the present time?

2. On what type of construction has each type of joint been used? Give weight of rail, length of rail, type of rail, type of roadbed, kind of pavement adjacent to rails, and character of traffic.

3. What is the average efficiency of each type of joint, i. e., its electrical resistance compared to an equal length of rail? Give length of joint used in testing.

4. About what is the average life of each type of joint? Give the percentage of failures for each year after installation.

5. What is the total cost of each type of joint on new work? What is the cost of replacing a joint which has failed? (See note to question 16 under "Rail bonds.")

6. What is the most prevalent cause of failure in each type of joint?

7. What are the maximum and minimum temperatures to which your welded joints are subjected?

8. With what types of joints and under what conditions do you use expansion joints in your rails?

In answer to the above inquiries, 42 companies, or 32 per cent of those addressed, submitted replies. This percentage, although not large, was considered as satisfactory and encouraging. The mileage represented in the replies was about 8600 miles of single track and represents nearly 20 per cent of the mileage in the United States. The constant demand upon public-service corporations from outside sources for statistics and information has assumed such proportions that it is little wonder that a large number of them have been disregarded altogether. Information is sought by engineering committees, colleges, State and city commissions, Government bureaus, and private engineers, and unless accompanied by an authoritative request such communications frequently are pigeonholed or find their way into the wastebasket. The generous number and the nature of the replies received, as well as the apparent willingness on the part of the companies to cooperate with the Bureau in its investigation, were complete vindication for the attempted study. The attitude

of the companies toward the matter is illustrated by the following statement from L. P. Crecelius, superintendent of power for the Cleveland Railway Co. and president of the engineering association of the A. E. R. A. for the year 1914–15.

> We agree in the suggestion that a study of the question of rail bonds is very important. Examination of the practice in regard to rail bonds reveals a wide difference in opinion as regards both the type and character of rail bonds and the method of applying them. We consider the subject not only important, but timely, and take pleasure in replying to your circular letter requesting cooperation.

With but a single exception the answers were submitted in good form, and the majority of them showed considerable labor in their compilation. A few replies showed the marks of a hasty and cursory survey of the subject, but these constituted only a small minority.

Below is given a list of the companies and their equivalent single-track mileage from whom replies to the circular inquiry were received. They are listed and numbered in the order in which the replies were received, and hereafter, for the sake of brevity, will be referred to by number rather than name. The mileage here given was taken from the McGraw Electrical Directory of August, 1915:

	Miles.
1. Union Electric Co., Dubuque, Iowa	21
2. Ohio Electric Railway Co., Springfield, Ohio	617
3. Indianapolis Traction & Terminal Co	158
4. Milwaukee Electric Railway & Light Co	403
5. Dallas Consolidated Electric Street Railway Co	50
6. United Railroads of San Francisco	280
7. Helena Light & Railway Co	24
8. Scranton Railway Co	100
9. Puget Sound Traction, Light & Power Co., Seattle, Wash	499
10. Connecticut Co., New Haven, Conn	171
11. United Railways & Electric Co. of Baltimore, Md	405
12. Houston Electric Co	75
13. Spokane, Portland & Seattle Railway Co	240
14. Chattanooga Railway & Light Co	61
15. St. Joseph Railway, Light, Heat & Power Co	49
16. Harrisburg Railways Co	72
17. Omaha & Council Bluffs Street Railway Co	140
18. Metropolitan Street Railway Co., Kansas City, Mo	265
19. Memphis Street Railway Co	124
20. Tacoma Railway & Power Co	104
21. Everett Railway, Light & Water Co	17
22. Butte Electric Railway Co	35

	Miles.
23. Terre Haute, Indianapolis & Eastern Traction Co.	101
24. Louisville Railway Co.	150
25. San Francisco-Oakland Terminal Railways.	256
26. Portland Railway, Light & Power Co., Portland, Oreg.	299
27. Minneapolis Street Railway Co.	435
28. Pacific Electric Railway Co., Los Angeles, Cal.	1,057
29. Los Angeles Railway.	383
30. Omaha, Lincoln & Beatrice Railway Co.	56
31. Birmingham Railway, Light & Power Co.	154
32. United Railways Co., St. Louis, Mo.	442
33. Interborough Rapid Transit Co., New York, N. Y.	167
34. Rhode Island Co., Providence, R. I.	399
35. New York Central & Hudson River Railroad Co.	254
36. United Traction Co., Albany, N. Y.	103
37. Cleveland Railway Co.	344
38. Peoples Railway Co., Dayton, Ohio.	31
39. Pennsylvania Railroad Co.	99
40. Cleveland Southwestern & Columbus Railway Co., Cleveland, Ohio.	225
41. Philadelphia Western Railway Co., Upper Darby, Pa.	50
42. Washington, Baltimore & Annapolis Electric Railroad Co.	100

Realizing that the information obtained from formal replies to a set of questions could be greatly strengthened and its value enhanced by personal interviews with the engineers of a number of companies a representative was placed in the field for that purpose. His itinerary included Harrisburg, Baltimore, Philadelphia, New York, Boston, Buffalo, Cleveland, Cincinnati, Indianapolis, Louisville, Richmond, and about 20 other intermediate cities and towns. During his five weeks' tour he interviewed upward of 50 electric railway engineers and visited a number of manufacturing establishments.

The information obtained on this tour, while not abounding in figures and percentages, forms a valuable supplement to the carefully prepared and conservative statements and tabulations contained in the formal answers and will be included when possible in the summations which are to follow.

Owing to the large number of questions asked and to the nature of the answers the material does not well lend itself to a condensed tabulation. Little could be gained by such a summary owing to the indefiniteness of the replies and the fact that they consist largely of estimates and opinions.

A more satisfactory presentation of the data and the one which will be employed is a tabulation of figures, facts, and opinions

under the several questions asked, to be followed by an analysis of all available data, with recommendations, under the various types of bonds, joints, and methods in use.

As the amount of material collected is so large as to preclude it from publication in full, summaries will be made where practicable. On points of particular interest and on which a lively difference of opinion exists or on which opinion has not yet crystallized the information as received will be given in full.

While there is, of course, no thought or desire of injuring or depreciating any product of any manufacturer, a frank and impartial discussion of all materials and methods is essential to the best results of the investigation. Such discussion, it is believed, will not injure any standard product or method, but, on the other hand, will benefit the manufacturers in helping the companies to standardize on certain products, thereby relieving the factories from continuing the manufacture of the great variety of types that are now demanded by the trade.

2. COMPILATION OF DATA SUBMITTED BY OPERATING COMPANIES ON BONDS

(*a*) QUESTIONS 1, 2, AND 3. NUMBER AND TYPES OF BONDS.—These questions ask for the sizes and types of bonds which have been used, for the type of construction on which each type of bond has been used, and for the number of each type in use at the present time.

In answer to the first question a majority of the companies enumerated a number of types of bonds as having been used in the past and stated that most of the early types had been replaced by modern bonds. The following answer from the Louisville Railway Co. is given to show the great variety of bonds which have been employed since the early days of electric railway engineering and serves admirably as an historical sketch of the development of the practice as well as an example of the experimental efforts which the roads have resorted to in their attempt to suitably bond their tracks.

LOUISVILLE RAILWAY CO. (MOTIVE POWER DEPARTMENT)—RAIL BONDS

A. No. 6 bare tinned copper wire bent around a ⅜-inch copper rivet in each end and placed outside of splice. On some occasions soldered to a continuous wire of same size running along the track; used about 1889.

B. 4/0 Chicago bond, solid type, used outside of splice bar, rivet driven in from back; used 1894, 1895, and 1896.

C. 4/0 solid crown bond adopted in 1897; used outside of splice. Steel drift pin driven in from front.

D. In same year tried on 2 miles of track the Bryan and brass washer, bolted type, using two pieces of 1/0 trolley or two pieces of 4/0 insulated.

E. Used in 1899 and 1900, 300 4-inch protected bonds (4/0 flexible), which were put on with screw compressor—T rail. They were too short to allow for contraction and were replaced a few years later by 12-inch crown bonds.

F. 300 000 c. m., 500 000 c. m., and 1 000 000 c. m., cable "Buffalo" bonds, cast-brass terminals threaded for nut, bolted, soldered, and tinned on web of 9-inch girder rail; 1899 to 1901.

G. 8½-inch to 12-inch flexible (4/0) crown riveted bonds used under Atlas and continuous joints on T-rail track, interurban and park line 1902 to 1907.

H. Adoption of same type on 9-inch girder rail.

I. 68-inch and 61½-inch solid (4/0) crown riveted cross bonds.

J. Previous to this cross bonding had been done by soldering continuous wire to stubs.

K. Adoption of solid terminal, compressor type, except where compressor could not be used around special work, short bonds flexible, long ones solid; 1908.

L. Installation in 1910 of exposed brazed ribbon bonds outside head of rail on 40 miles 70-pound T track; interurban. Found large number of these bonds broken in succeeding years, partly due to loose and low joints.

M. A trial in 1910, on one side of 6½ miles of an interurban line 1000 of the American Steel & Wire Co.'s twin terminal type; 75 per cent stolen in 1913–14 and the rest removed.

N. Returned in 1913–14 to 4/0 crown flexible compressor type under continuous joints on all open track.

O. Cross bonding on 70-pound T rail in country by pieces of 70-pound rail turned upside down, welded to base of running rail every 1000 feet, during 1914.

P. Welding 300 or more pairs of splice bars (1914) on 7-inch and 9-inch girder rail, city construction, using Indianapolis arc welder.

Q. One bond to each joint is used on 60-pound or 70-pound T rail or old light girder rails. One, two, or three bonds each joint on 7-inch or 9-inch girder rail in the city, according to headway of cars.

R. All bonds attached to web of rail except in items L and M, which were attached to rail heads.

Expanded bonds, A, B, C, D, G, H, I.

Compressed bonds, E and K.

Soldered bonds, F.

Standard type bonds, G, H, K, M, N.

Question 2, as to the type of construction on which each type of bond had been used, was not asked so much with the idea of determining what bond is best suited to a given type of construction as to determine, if possible, the causes of reported bond failures. In a few instances the answers lend themselves

to such interpretation and will be employed in the discussion of that subject.

In answer to the third question 36 of the 42 companies gave some figures as to the number of bonds in use at the present time. In some cases their figures were not complete, but were given for only one or more types of bonds in use or for bonds installed since a given date. The number of bonds reported, therefore, is only a fraction of the total number represented by the 36 companies answering this question, but nevertheless undoubtedly give a fair indication of the relative number of each type that has been installed in recent years throughout the country.

The 2 305 300 bonds reported are classified as follows:

Compressed terminal:	
Ribbon, concealed	214 200
Stranded, concealed	338 100
Stranded, exposed	176 300
Not described	201 000
Total	929 600
Pin terminal:	
Stranded, concealed	241 100
Stranded, exposed	63 200
Not described	58 500
Total	362 800
Electric weld:	
Exposed	392 600
Concealed	27 400
Not described	300 000
Total	720 000
Soldered, all kinds	140 800
Twin terminal	113 700
Oxy-acetylene, welded	15 000
Channel pin	20 000
Plastic alloy	3 400
Total	292 900
Grand total	2 305 300

These figures show that among the companies reporting the use of compressed-terminal bonds is in excess of that of any other type, with the electric-weld bond second.

For concealed application the stranded bond is a favorite over the ribbon type, the percentages being 61 and 39, respectively, in the compressed-terminal type, while no concealed-ribbon bonds of the pin-terminal type were reported.

The largest number of bonds reported was 315 000 by Company 28. Of these 300 000 are electric-weld and include both head and web types, the relative numbers not being given.

The second largest number of bonds reported was 243 000 by Company 35. Of these 81 000 are soldered bonds on third rail and 162 000 pin-terminal, stranded bonds. Company 6 reports the use of 199 500 bonds, 196 000 of which are said to be compressed terminal. They no doubt include all varieties of that type and are listed as "not described." Of the 720 000 electric-weld bonds in use 300 000 were reported by Company 28 and 160 000 by Company 2, and of the 113 700 twin-terminal bonds 60 000 were reported by Company 11. The 15 000 oxy-acetylene-welded bonds are used by Company 27. The two million bonds and more reported are sufficient to single bond 30-foot rails on 6550 miles of single track. As this is about 75 per cent of the mileage represented by the answering companies, it is safe to assume that a large percentage of bonds in use were reported.

(*b*) Question 4. Inspection of Bonds.—Forty-two answers to this question are briefly summarized as follows: Fifteen companies do not inspect bonds regularly; 6 companies test bonds by inspections and melting snow only; 2 companies test bonds every 3 months; 10 companies test bonds every 6 months; 12 companies test bonds every 12 months; 1 company tests bonds every 18 months; 3 companies test when bonds are apparently in bad condition; 4 companies employ an autographic-recording bond-testing car; 23 companies employ some kind of portable bond tester; and 1 company tests exposed soldered bonds with a hammer.

These figures indicate that all degrees of inspection and testing are employed from the observance of joints around which snow is melting to frequent tests with accurate instruments. While the majority of the companies aim at regular inspection and testing, numerous interviews revealed the fact that such aims are not always realized. Testing is frequently done by men who have other regular duties to perform and who give their time at irregu-

lar intervals to this work, and this time may not always be sufficient to comply with the standards set by the company. Moreover, in times of financial stress this feature of maintenance is frequently considered as unnecessary and is consequently slighted. Even were it carried out, the funds for following up the replacement of poor bonds are not always available.

Several companies state that the condition of exposed bonds is determined by inspection only, instrument tests being confined to concealed bonds. While bonds can be quickly inspected by trackwalkers this does not always give assurance of their good condition. Mechanically applied and soldered bonds frequently develop high resistances when no indication of such is apparent from inspection. A hammer blow gives a better indication of conditions, but of course is not always infallible.

It should be pointed out that failure to test bonds regularly and systematically is not always an indication of carelessness or unconcern on the part of an operating company. A test of bonds is of little value unless followed up by repair. It frequently happens that a systematic repair of bonds, as a bonding proposition only, is not justifiable owing to the fact that a general rehabilitation of the system may be in progress or in contemplation, which in the course of a very few years would weld or otherwise repair all joints. Under such circumstances a company might not be justified in repairing any but the very worst joints, and these as a rule can be detected either by inspection or by melting snow. This condition while not often existing over an entire system is frequently met with in limited areas or regions, where it becomes necessary to maintain an old track for from one to three years to await the city's order for change of grade or for repaving. A general repair of bonds under such circumstances might not be advisable, and again only open joints would receive attention.

(*c*) QUESTION 5. CRITERION FOR REPLACEMENT.—Upon this point widely varying standards appear to be in practice. Twenty-six companies of the 42 have a definite resistance below which they aim to maintain all joints, the resistance being defined in terms of equivalent length of adjacent rail. Other roads bond only when joints are open or bonds are broken, or where snow is found

to be melted. The summary following is compiled from answers submitted to question 5.

TABLE 1

Criterion for Bond Replacements

Number of companies	Criterion for replacement (3 feet of joint equal to feet of rail shown)		Number of companies	Criterion for replacement (3 feet of joint equal to feet of rail shown)	
	City	Suburban		City	Suburban
	Feet	Feet		Feet	Feet
1	3½	.....	1	8	27
2	3¾	.....	2	9	.....
1	4	.....	2	10	.....
1	5	.....	2	10	.....
5	6	.....	1	15	.....
1	6	12	2	20	.....
2	7	.....	6	(a)	.....
2	8	.....	9	(b)	.....
1	8	12			

[a] Open bond or melted snow, or when 50 per cent of strands are broken. [b] No answer.

Joints showing a resistance of 4 feet of rail or better are, as a rule, bonded with two or more bonds, and are confined for the most part to heavy traction lines such as exist in New York City. The average value of the figures for city streets is 8.3 feet.

(*d*) QUESTION 6. AVERAGE LIFE OF BONDS.—The answers to this question are so vague and inconsistent and the failure of bonds are affected by so many conditions and circumstances that it is difficult to draw definite conclusions from them. The fact that the life of a bond depends in a large measure upon the life of the joint was brought out by a large number of the answers. Few figures and statistics giving percentages of failures and the life of various bond installations were submitted. The question is one of such great importance and the answers of so much interest that a number of them are here quoted.

COMPANY 3.—The brazed type of bond shows a failure of 2 per cent, which is caused by loose rail joints, and is not charged against the bond. The compressed type shows no failures chargeable to bonds. * * * Where the failures of compressed type of bonds may appear unreasonable, we have no record of this type of bond failing in the past 10 years other than due to rail breaks or where joint becomes so loose that it

would gradually break the strands and separate the bond. All of our bond terminals are carefully tinned before compressing in the rail. We take particular pains in grinding our drills so as to make a smooth, clean hole in the rail, and also keep the bond compressor in good condition so as to get an even compression on the bond terminal. We have kept this practice up for 10 years and find that it is giving excellent results, and we now figure the life of a bond longer than the life of the rail.

This company uses stranded bonds and continuous splice bars.

COMPANY 4.—We have approximately 34 000 soldered leaf bonds on our open track. Of these about 3500 were replaced in 1912, about 2200 in 1913, and about 5100 in 1914. Our records do not show the percentage failure by years after installation.

COMPANY 5.—The life of a bond we have found to be determined entirely by the life of the joint, i. e., so long as the bolts remain tight and the joint in good service, just so long will the bond be good. In nearly all cases where defective bonds have been removed it has been found that the joint itself was loose and by its vibration the bond would become detached from the rail or at least become loosened.

This company employs stranded pin-terminal bonds.

COMPANY 6.—The life of a bond depends almost entirely upon the rigidity with which the rail joint is maintained. With an absolutely unmovable practically homogeneous rail joint one bond would last about as long as another and all would last until the rail was worn out. Data about "average life" of bonds would be misleading. Such data has not been kept. Our experience has taught us to prefer short expanded terminal, concealed, ribbon bonds where permissible.

Company 7 uses twin-terminal soldered bonds and renews them when they show a resistance greater than 15 feet of rail. In answer to question 6 they say:

COMPANY 7.—The average life of the bond is about 6 years. Nearly all of the failures were either due to poor workmanship in putting them on, or to the loosening of the splice bars which allowed a movement of the rails to break the strands of the bond.

COMPANY 8.—We have no data on which to base the probable life of the different types of bonds. It has been our experience that the mechanical condition of the joint fails before the bond. Consequently the failure of the bond is then due to the poor mechanical condition of the joint. Should the joint be maintained in good mechanical condition and the bond is properly installed, cases have been noted where the bond did not show any depreciation after 8 to 10 years of service. These instances are rare, for the reason that the mechanical condition of the joint usually requires attention before that period, and the bond is also replaced.

From our experience the life of the exposed bond is greater than that of the concealed type, probably due to the fact that the mechanical condition of the track is usually better.

COMPANY 10.—The life of the bonds, we find, vary from 3 to 12 years. The percentage of failures can not be stated at this time.

COMPANY 11.—Twin-terminal and compressed-terminal bonds usually last as long as the track, the percentage of failure is very small. The percentage of failure of soldered bonds is extremely high; we have no definite figures.

COMPANY 12.—The average life of these bonds is about 6 years.

This company uses stranded concealed pin-terminal bonds.

COMPANY 13.—Our soldered bonds, after 7 years, are practically all off, and 50 per cent of them were off in half that time. Our experience with these bonds has been that the few bonds which we were able to get on properly gave excellent results, but on the average it was impossible to get these bonds so soldered to the rail that they would stand under heavy traffic.

At the present time our interurban lines outside of the city, consisting of about 150 miles, are virtually all bonded with the welded bonds.

We aim to make an inspection of our bonds at least once a year. Our trouble with the welded bonds has been the breaking of the leaves of copper just below the lug which is welded to the rail. This is doubtless due to the weakening of the metal through heating at the time the weld is made. Vibration and the deflection of the joint tend to work the leaves till eventually they snap off close to the lug. We have endeavored to overcome this by having the bond people furnish us with a welded bond with the terminal in the shape of a T, so as to overcome any bending of the leaves by deflection at the joint. We have not had these experimental types of bonds on long enough to tell whether the cure is going to be effective.

In the case of the pin-terminal bond, the only trouble experienced has been the loosening of the terminal by reason of incomplete expansion when driving the pin. These bonds have to be very carefully put on or they will work loose under the plates. The compressed-terminal bonds have given us better satisfaction in this respect.

The following table, giving percentage of failures for various types of bonds, is extracted from the report of Company 14:

TABLE 2

Company 14. Bond Failures

Kind of bond	Between rails	Percentage of failures	Years since installation	Length in miles under consideration
4/0-10-inch, compressed	Brick	23	1	1
4/0-10-inch, compressed	Asphalt	39	1	¼
4/0-13-inch, compressed	do	22	1	1
4/0-36-inch, compressed	Wood block	69	1	1
4/0-10-inch, compressed	Macadam	50	1	1
4/0-10-inch, compressed	Brick	4	2	1½
4/0-13-inch, compressed	Open	20	2	6
4/0-10-inch, compressed	Brick	6	3	2
4/0-10-inch, compressed	Asphalt	39	3	1
4/0-10-inch, compressed	Macadam	19	3	3
4/0-10-inch, compressed	Open	46	3	7½
4/0-10-inch, compressed	Brick	3	4	2
4/0-10-inch, compressed	Asphalt	4	4	½
4/0-36-inch, compressed	Macadam	35	4	½
4/0-10-inch, compressed	Open	19	4	4½
3/0-10-inch, compressed	do	39	4	1½
4/0-36-inch, compressed	do	24	5	½
4/0-10-inch, brazed	Brick	3	5	3

COMPANY 16.—The life of a bond depends almost entirely upon the type of track construction. In first-class construction, such as we use in paved streets, we never have a broken bond, and the depreciation is confined to a slight corrosion of the strands, and in a few cases a corrosion of the terminals. The latter only occurs where the bond has not been properly applied.

In open-ballast construction, expansion and contraction of the rail must be allowed for in the joint. This, with defects in track construction, such as loose bolts, poor foundation, etc., causes the strands on the bonds to break. On suburban lines the record for the year 1914 is as follows:

Number of joints tested	Defectives		Type of joint	Weight of rail	Age of installation
	Number	Per cent			
				Pounds	Years
2590	29	1.1	Weber	65	8
1454	40	2.75	Channel	65	10
2086	74	3.50	do	56 and 65	20
364	28	7.8	do	60	14
1182	64	5.5	Continuous	70 and 85	7

COMPANY 17.—Up to the present time we have noticed no failure of the brazed bonds.

COMPANY 19.—Bonds will last indefinitely if rail joints are kept in good repair.

COMPANY 22.—No record. If the bond is correctly installed and the rail joint is perfect, I see no reason why the bond should not last as long or longer than the rail.

COMPANY 23.—I am unable to state what is the average life of each type of bond, but in my opinion the short bond attached to the head of the rail will, as a rule, last 3 to 6 years and the larger compressed-terminal bond around the splice will have an average life of approximately 12 years. The life of all bonds depends entirely upon the track conditions. If it were possible to keep the joints absolutely tight under all conditions it is quite possible that the life of the bond, especially of the longer type around the splice, would be equal to the life of the rail.

COMPANY 24.—Brazed bonds, 7½ years; compressed bonds, 15 years.

Company 25 submitted a table showing the cause and rate of failure of about 10 different sizes and types of bonds. All types show a high rate of failure with the exception of the compressed terminal, installed with mercury alloy, which shows no depreciation. This type, however, is the only one used on paved streets with concrete roadbed, and this type of construction no doubt has more to do with their good performance than the type of bond itself.

COMPANY 26.—Can not state average life of bonds. The failure of compressed-terminal bonds has been very light, probably not 2 per cent in six years; on twin-terminal bonds would estimate 5 per cent failure in five years. The soldered bonds have been unsatisfactory. We have found it impossible to maintain them in good condition.

COMPANY 27.—We find that all pin-terminal bonds, expanded in holes in the rails, after a comparatively short life of low resistance begin to blacken at contact, with resulting high resistance within one year after installation. We find that with soldered terminals the solder disintegrates either from vibration or electrolytic action, and that within one or two years a high resistance results. This is also true where heavy lugs are soldered onto the rails for the purpose of connecting cables.

COMPANY 29.—Ten-inch compressed-terminal ribbon bonds have been in service over 10 years; no trouble from breakage. All concealed bonds have an average life of from 5 to 15 years, depending upon maintenance of plate bolts from loosening up.

COMPANY 31.—The life of a bond depends more on the condition of the rail joint than any other feature. We have never kept any records that would give us actual life of bonds under various conditions, but we believe that in our recent concrete paving construction, where we desire rail joints tight and pay special attention to their installation, the life of the bonds will equal the life of the rail and paving, which will be from 10 to 25 years, depending on the quantity of traffic. We believe further that on some of our old track of 56 and 60 pound rail, either in open work or chert paving, where the rail joints are very bad, the life of the bond is probably only a few months, or at least one year.

COMPANY 33.—On account of the fact that the life of the bond in a track rail is contingent on the life of the rail, and as the life of this track rail is comparatively short, due to the high frequency of service and the heavy car mileage, an estimate of the average life of the bond would not be reliable and might be misleading.

Regarding the life of bonds on the contact rail, would advise that except in isolated instances the bonds show no appreciable deterioration after a life of 12 years.

COMPANY 34.—In 1899 about 6 miles of 70-pound, 60-foot rail, single track, was laid in country road, dirt ballast, bonded with two 36-inch, 4/0 stranded bonds with expanded head. Tested 8 years after installation, showed no defective joints. Tested 15 years after installation, showed about 4 per cent defective joints.

In 1901 about 30 miles of single track was laid in country roads with 70-pound T rail, 60 feet long, bonded with one 8-inch and one 17-inch, 4/0 concealed bond with expanded head, around each joint. These bonds were tested in 1914 and showed about 4 per cent defective.

In 1904 about 21 miles of single track was laid with 9-inch girder rail, 60 feet long, 98 pounds per yard, gravel ballast, and block and macadam paving. Bonded with two 12-inch ribbon, 4/0 bonds, with compressed heads. Tested in 1907, no defective joints; tested in 1914, showed about 5 per cent defective joints.

In 1913 we rebonded somewhere over 5000 joints on 60 and 70 pound T rail, 30 and 60 feet long, with 9-inch 300 000 c. m. ribbon bonds welded to ball of rail. Tested in 1914, no defective joints.

COMPANY 35.—Average life of bond not yet determined. Percentage of failures: 1909, 0.15 per cent; 1910, 0.069 per cent; 1911, 0.082 per cent; 1912, 0.064 per cent; 1913, 0.047 per cent; 1914, 0.098 per cent.

This company uses pin-terminal stranded bonds.

COMPANY 36.—I can not give you definite information as to the average life. In 1913, 0.86 per cent of bonds were replaced; 1914, approximately 0.1 per cent.

This company uses pin-terminal stranded bonds of various lengths.

COMPANY 37.—Life of bonds has been found to depend very largely upon the type used and its exposure to vehicle traffic, tampering, and theft. A loss of 2 per cent as failures in brazing rail bonds to the rail we have found to be an average figure and as representing the failures due to defective brazing, which, however, are checked up and corrected as the work progresses and such defects are made good. The brazes show a remarkably effective life, and failures seem to take place in the breaking off of the strands next to the terminal. Our experience for the last few years indicates that a thousand bonds per year become defective because of theft, mutilation by vehicles, and breaking off of strands at the terminal, or based upon the total number of bonds we have in service this is approximately 1.5 per cent loss per annum. We have bonds in service which were brazed to the rails 10 years ago.

COMPANY 38.—Over 30 miles of track which has been installed from the year 1894 to the present time the percentage of failure you will find as follows: Special work—open, 235; defective, 81; main track—open, 181; defective, 129; giving figure of merit, 87.8.

These figures were derived from autographic records recently made by bond-testing car.

COMPANY 39.—The average life of each type of bond varies in our installation. The exposed type of bond is used in tunnels and station area, and in three years we have had to renew 65 bonds, or about 0.4 of 1 per cent of the total number installed in these sections.

Of the concealed type we have had to renew 1200, or about 5 per cent of the total number of bonds installed. The large renewal is confined to one section, which is on built-up ground where high speed with heavy traffic loosens the joints. We have also found that in some cases the splice bars squeeze the strands of the bonds and they eventually break off. This of course is not due to defects in design and manufacture of bonds. The percentage of failures for the first year was less than 1 per cent, and for the past two years was a little over 0.1 per cent, and for the last year was about 2 per cent.

COMPANY 40.—About 5 per cent of the solder type of bond will need replacing at the end of first year and about 20 per cent at end of second year, after which the depreciation is much faster. We do not believe that the average life of installation of solder bonds will run much over 3 years.

The average life of the pin-terminal type of bond is from 4 to 6 years; the depreciation of contact, however, is very marked before the elapse of this period. The resistance increases about a third at end of first year and has about 50 per cent more resistance after the third year than at installation, while at the end of the 4 years, besides the increase in resistance, we have found about 40 per cent of bonds out of rail.

The welded bond shows no increase in contact resistance during our 11 years of use. If joints are not kept tight, failures will occur, due to strands breaking. It is hard for us to set a percentage of failure, for we have found that on lines where the track is kept in good condition the bonds have not depreciated in any way. Up to the present time we have replaced about 1 per cent of these bonds a year, due to joint depreciation, theft, and careless workmen.

COMPANY 41.—Practically all of the compressed bonds are giving good service after 9 years of operation, the life of the road. Have had some trouble with electric-welded bonds due to faulty installation during construction.

COMPANY 42.—Since our company began operation, February, 1908, from the maintenance standpoint we have replaced 7357 bonds.

This is on an installation of 33 000 twin-terminal bonds and amounts to 3 per cent per year.

(*e*) QUESTION 7. INTERVALS FOR CROSS BONDING.—The following figures show the intervals at which the companies cross-bond in city streets:

	Feet
2 companies	100 to 200
4 companies	300
16 companies	500
4 companies	600
10 companies	1000
1 company	1500
2 companies	3000

As a rule these figures apply to both single and double track, although four companies bond the two tracks on double-track construction at greater intervals than they do the two rails on each track. Eight companies cross-bond open and suburban track at greater intervals than city track. One company employs no cross bonds, owing to the use of block signals. Two companies install cross bonds directly beneath trolley feed taps in order that they may easily be located at any time.

(*f*) QUESTION 8. SIZE OF CROSS BONDS.—With but few exceptions the companies appear to have no other than an arbitrary basis for determining the size of cross bonds. Twenty-one of the 42 answering use 4/0 copper exclusively, while 11 proportion their cross bonds to accord with the load on the rails and the distance from the power house. One company cross bonds with copper 20 per cent greater than the combined capacity of feeders and trolley.

(*g*) QUESTIONS 9 AND 10. BONDING AROUND SPECIAL WORK.—With but a single exception the 42 companies use supplementary copper around their special work in addition to bonding through it. The type of bond terminal used for this and cross bonding is with nearly all companies the same as that employed on their straight work, extra lengths of copper being soldered to the terminals when needed. A few roads using compressed-terminal bonds on straight work resort to pin-terminal bonds on special work, owing to the difficulty of using a compressor in the sharp

angles of the frogs. With regard to this feature, Company 3 states that they now order their frogs with an extra foot of rail, thereby permitting the use of the compressor in all cases.

(*h*) QUESTION 11. THEFT OF BONDS.—Thirty-four of the 42 companies report the loss of bonds by theft in varying extents. With 16 of these the trouble has been chronic, while with 18 it has been slight or infrequent. It has been much more serious on soldered bonds than on other types, owing to the comparative ease with which these can be removed. Cross bonds and jumper bonds have been stolen in great numbers, even where they were buried in the earth. On open construction the only way of safeguarding long bonds appears to be to concrete them in. One company reports that after losing many cross bonds this method of protecting them was resorted to and so incensed the thieves whose revenue had thus been eliminated that they cut and mutilated the bonds at the terminals, apparently for spite. Theft of copper is not confined to bonds, but trolley wire and even No. 8 ground wires have been known to disappear overnight. Company 40 reports that in the past 11 years 350 welded bonds and 3500 soldered bonds have been stolen. Company 42 states that in 7 years 800 twin-terminal bonds have been stolen, the total number installed being 33 000. These are the only roads giving definite figures on theft of bonds.

(*i*) QUESTION 12. GRADE OF LABOR FOR BONDING.—The question as stated is ambiguous, owing to the different interpretations placed on the words "skilled" and "unskilled." With some companies a skilled laborer is one who has had considerable experience in applying bonds, although he may not have had training as a machinist. With other companies only experienced mechanics would be considered as skilled. In view of the existence of this ambiguity, the answers received to this question do not always give a definite idea of the grade of labor employed.

The following brief summary of the answers is given with no attempt at interpretation: Fifteen companies use skilled laborers; 10 companies use unskilled laborers; 8 companies use a skilled foreman and unskilled laborers; 7 companies use experienced laborers; 2 companies use skilled laborers for welded bonds and unskilled laborers for mechanically applied bonds.

(*j*) QUESTION 13. BONDING TOOLS.—As the answers are not complete, it is impossible to say how many companies use the hydraulic and how many the screw compressor, or to what extent power drills are used in preference to hand drills. No summary of answers to this question will be attempted.

(*k*) QUESTIONS 14 AND 15. DRILLING.—Twenty-one companies use no lubricant of any kind in drilling holes for bonds, 4 use water only, 8 use soapy water, 2 use lime or soda water, 3 use oil, 19 roads grind drills by hand, and 13 roads grind drills by machine.

(*l*) QUESTION 16. COST OF BONDING.—The cost of bonding is extremely variable, depending upon the locality, the price of copper, whether holes are punched at factory or drilled on the job, whether joint plates are applied by bonding gang, whether work is new or repair, whether traffic interferes or not, and upon a great many other factors. As average values, therefore, would have little significance, no attempt at tabulation of bonding costs will be attempted. A few specific quotations giving conditions under which the work was accomplished will be of much more value and are therefore given in this form.

Company 2 gives the following unqualified figures:

10-inch 4/0 compressed terminals	$0.65
8½-inch 4/0 electric weld	.50
36-inch 4/0 welded to web	.95
8-inch twin terminal	.55

Company 4 gives the cost of—

Standard leaf bonds, soldered	$0.45
250 000 cir. mils cross bonds soldered	2.00

COMPANY 5.—Cost of installing one 9-inch flexible-crown pin-rail bond we estimate as follows:

Bond	$0.40
Labor	.30
Tools	.05
Total	.75

COMPANY 6.—Compressed terminal, new work. Holes drilled at factory:

Labor	$0.04
Bond	.417
Miscellaneous	.0045
Total	.4615

COMPANY 7.—Operating full day, installing twin-terminal bonds:

Bond	$0.35
Labor	.15
Gasoline and solder	.03
Miscellaneous	.0035
Total	.5335

TABLE 3

Company 8. Bonding-Installation Costs

Rail where bond was applied	Head		Web		Head		Web					
Type of bond	Brazed to head	Twin ter.	Comp ter.	Pin ter.	Brazed to head	Twin ter.	Comp or pin ter.	Brazed to web	Comp ter.	Pin ter.	Comp ter.	Pin ter.
Length of bond (inches)	8	Reg.	10	10	8	Reg.	10	40	40	40	10	10
Size of bond	4/0	4/0	4/0	4/0	4/0	4/0	4/0	4/0	4/0	4/0	4/0	4/0
Cost of bond	$0.33	$0.36	$0.46	$0.46	$0.33	$0.36	$0.46	$0.80	$0.80	$0.80	$0.46	$0.46
Labor cost (installing bond)	.10	.06	.10	.08	.17	.17	.25	.25	.25	.20	.25	.20
Labor cost, removing and replacing splice bars	.....	.....	.....	.....	.....	.....	.40	.....	.....	.....	.40	.40
Labor cost, paving	.....	.....	.....	.....	.....	.....	.....	.40	.60	.40	.50	.50
Paving materials	.....	.....	.....	.....	.....	.....	.....	.60	1.00	.60	.80	.80
Interest and depreciation on tools and appliances	.07	.001	.02	.02	.07	.001	.001	.07	.02	.02	.002	.002
Cost of electrical power	.02	.002	.002	.002	.02	.002	.....	.02	.002	.002	[illegible]	.....
Joint material	.....	.....	.....	.....	.....	.....	.20	.....	.....	.....	.20	20
Miscellaneous supplies and expense	.02	.026	.01	.01	.02	.026	.01	.01	.01	.01	.01	.01
Total cost	.54	.449	.592	.572	.61	.559	1.321	2.15	2.682	2.032	2.622	2.572

COMPANY 11.—Cost of installing twin-terminal bonds in quantities 11 cents to 15 cents each, exclusive of cost of bond. Cost of installing pin or compressed terminal bonds where holes are only reamed, 25 cents per joint where two bonds are installed.

COMPANY 13.—The cost of installing the welded bond is about 20 cents each, exclusive of cost of bond, renewals under traffic about 36 cents, and cross bonds 64 cents. The latter are placed on the web of the rail.

COMPANY 14.—Total cost of installing thermo bonding 100 new 36-inch 4/0 bonds in open track:

100 new 4/0, 36-inch compressed bonds	$82.46
Labor, drilling and applying new bonds, 2 men and 1 foreman, 3 days	20.00
25 pounds thermite, at 30 cents	7.30
½ pound powder, at $1.25	.63
Cost of tools and depreciation	2.00
Total cost	112.59
Cost per bond	1.13
100 new 10-inch 4/0 compressed bonds in open track, itemized as above (per bond)	.76
(Cost of rebonding with 36-inch, 4/0 compressed bond same as for new work, with credit of $0.105 per bond for scrap.)	
Cost of rebonding exposed track with 10-inch 4/0 compressed bond (each)	.89
Scrap credit (each)	.07
Net cost (each)	.82
Cost of rebonding around joints in brick pavement 10-inch 4/0 compressed bonds (each)	1.04
Scrap credit (each)	.07
Net cost (each)	.97

COMPANY 16.—Total cost per joint of double bonding with 4/0 compressed-terminal concealed bonds itemized as follows:

Two 4/0 bonds	$0.80
Labor drilling holes, applying bonds, and plates on 7 and 9 inch rail	.50
Depreciation at 15 per cent and interest at 5 per cent on $500 equipment equals fixed charges per year, $100.	
On basis of 700 joints per year	.14
Electric current, miscellaneous supplies	.06
Total	1.50
Same for T-rail construction	1.42

COMPANY 17.—The average cost of installing a 9½-inch brazed bond, inclusive of paving, is $0.6392. The labor costs are from records of 5710 bonds installed in 1913 and 1914. The highest labor cost was $0.85 per bond. This was at a point where four bonds only were installed and the traffic was heavy, so it was necessary to do this work at night. The lowest cost of labor per bond was $0.10, which was on open track where the service could be kept off most of the day. The cost of opening and replacing pavement is $0.25.

The following figures are from Company 20 and are based on 1000 bonds installed. All types are soldered bonds:

	Each.
38-inch cable bond	$0.3567
Type B. B. bond in paving	.59
Type A, 750 M c. m.	1.59
Horseshoe bond	.46
Type C twin terminal soldered	.808
B. B. bond open-track work, includes removing and replacing plates	.66
38-inch Clark 500 M c. m. bond	1.94

Company 23.—Our cost for installing 19 818 electric-weld bonds in 1912 was as follows:

Labor per bond	$0.13004
Material per bond	.3138
Total per bond	.44384

This does not include interest and depreciation of bonding car and tools nor cost of electric energy used.

The cost of labor for the compressed-terminal type bond will average from $0.50 per bond on new work to $1.25 per bond on old work. The cost depends largely upon the work required in taking up and replacing pavement.

Company 25.—(1) Single bonding, 70-pound A. S. C. E. rail, 4/0, 10-inch, compressed-terminal bond, no traffic, bond holes punched, electric current not used, joints in large numbers.

Labor:	
Removing and replacing angle bars	$0.08
Reaming bond holes	.07
Alloying bond holes	.04
Compressing-bond terminals, painting and adjusting	.109
Total	.299
Superintendence	.03
Tools, 2 per cent	.006
Material:	
One 10-inch bond	.363
Alloy	.05
P and B No. 1 paint	.012
Total	.425
Store expense, 2 per cent	.008
Total cost per joint	.768

(2) Double bonding, same as (1), $1.445 per bond.

(3) Single bonding, reconstruction, 141-pound P. S. Co. No. 263 rail, 450 000 cir. mil., ribbon compressed-terminal bond, bond holes punched, traffic under 20-minute headway, electrical energy not used, joints in small numbers. Itemized as above, $1.261 per joint.

(4) Single bonding, repairs, oiled macadam pavement, 70-pound A. S. C. E. rail, 4/0, 10-inch, compressed-terminal bond, holes not punched, traffic under 10-minute headway, electrical energy not used, track fastenings in good condition, joints in small numbers. Itemized as above, $1.38 per joint.

(5) Single bonding, repairs, asphalt pavement, same as (4), $1.971 per joint.

(6) Double bonding, same as (4), $2.21 per joint.

COMPANY 26.—Compressed-terminal, soldered 9-inch bond, $0.55; labor, $0.35; solder and gas, $0.10; total, $1. Twin terminal, $0.42; labor, $0.22; total, $0.64, exclusive of paving charges.

COMPANY 27.—Complete cost of installing oxy-acetylene-welded bonds of 250 000 cir. mils capacity in large numbers is between 50 and 60 cents per bond, including cost of tools and machinery.

COMPANY 31.—Brazed bonds, $0.56 in quantities; $0.70 to $1.55 for renewals. Compressed terminal, $0.69 in quantities; $0.75 to $2.30 for renewals.

COMPANY 32.—The cost of bonds given herewith includes the cost of the bond and the labor of installation for open-track work. A good many of the bonds are made in the company's shops, and the copper cost at which they are figured is 14 cents per pound. No interest and depreciation on the cost of tools used is taken into account, as these figures reduced to a per bond basis are considered negligible. This also applies to the cost of power.

72-inch compression bond	$1.25
39-inch compression bond	.95
33-inch compression bond	.90
22-inch compression bond	.75
22-inch head-compression bond	.40
Twin terminal	.61
9 inch crown, concealed	.98
7-inch soldered	.65

Company 33 submits the following table:

TABLE 4

Company 33. Bonding Installation Costs

Size of bond	Form of copper	Length	Number per joint	Roadbed	Cost per joint
		Inches			
4/0 (one joint)	Strand exposed	40	1	Elevated	$2.30
4/0 (one joint)	do	46	1	do	
300 000 cir. mils	do	23	2	do	1.99
300 000 cir. mils	do	26	2	do	
425 000 cir. mils	Strand semiconcealed	18	4	do	5.08
550 000 cir. mils	Ribbon exposed	5½	2	Ballast	1.98
400 000 cir. mils	Ribbon concealed	12	2	do	2.04
400 000 cir. mils	Strand concealed	12	2	do	2.04
300 000 cir. mils	do	9	4	do	3.04
300 000 cir. mils	Ribbon concealed	9	4	do	3.04
437 675 cir. mils	Solid concealed	3½	4	Elevated	2.48

Company 35 states that the labor cost of installing a pin-terminal bond is 35 cents. This figure is significant when considered in connection with the table giving percentage of failures on this road. More will be said later regarding the methods employed by this company in installing pin-terminal bonds.

Company 38.—Installing new bonds, large quantities:	
Drilling and reaming $\frac{17}{32}$-inch holes	$0.05
Compressing bond	.05
One 9-inch bond	.40
Electric current	.06
Depreciation	.05
Total	.61
Renewing bonds in pavement:	
One 9-inch bond	$0.40
Six T bolts	.24
20 paving bricks	.40
Cement and sand	.10
Electric current	.02
Labor	1.68
Depreciation	.28
Total	3.04

Company 40.—300 000 cir. mils solder bonds cost us 63 cents to install in large numbers and about 40 cents each on renewals.

The pin-terminal bonds cost us approximately $1 each to install in large numbers and about $1.75 each on renewals. The renewal price covers labor in taking off and putting back plates and using one-half new bolts.

The electric-weld bonds cost us 43 cents each to install on renewals. The above prices include all labor, current used, supplies, and the interest and depreciation on the tools and apparatus. No paving charges are included.

Company 42.—Twin-terminal bond: Bond, 35 cents; labor and tools, 15 cents; total, 50 cents.

(*m*) Question 17. Causes of Failure.—The companies are almost unanimous in stating that the principal cause of bond failures is vibration, resulting from loose rail joints. Two companies have given corrosion as the chief cause of failures while five state that many bonds fail from external causes, such as traffic and injury from workmen. Other causes of failure enumerated are expansion and contraction and poor workmanship.

The following characteristic quotations are selected from answers submitted to question 17:

Company 5.—The only cause of failure of pin-terminal bonds is either defective installation at the start or the loosening of bolts and the vibration of the joint.

COMPANY 8.—From our experience the causes for the failure of rail bonds have been twofold: (1) Improper maintenance of the mechanical condition of the rail joint, and (2) carelessness on the part of the laborer in the installation of the bond in question.

Our experience has been that 70 per cent of the defective bonds requiring renewal will be found at rail joints, whose mechanical condition is very poor. This has given the conclusion that a large percentage of bond failures is due to the poor mechanical condition of the joint.

Carelessness in the installation of the bond is brought about in several ways: (1) Imperfect drilling of the hole; (2) not wiping the hole clean of the lubricant used for the drill; (3) not cleaning the terminal of the bond thoroughly; (4) improper use of the bond press or other tools for installing the bonds; (5) crushing the bond between the splice bars and rail, when the splice bars are installed, and in the case of the brazed bond, "burning the bond" by allowing the welding or brazing temperature to become too high and thus making a poor contact between the bond and rail.

COMPANY 15.—The causes of failure are usually two. The contact corrodes or the rail splits through the bond hole. Frequently a split rail is shown up by the bond testing before any sign of split is seen at the head of the rail except probably the joint is a little loose.

COMPANY 20.—We have had only about five failures with the type C twin-terminal soldered bond since we started using them and in all cases failures were due to ballast becoming wedged between the bond and the rail and a defective wheel forcing the rock down and destroying the bond.

COMPANY 22.—Many compressed-terminal bonds have become loose in the rail through electrolytic action caused by poor contact. Have had no trouble of that kind with pin-terminal bonds. Most of our bond failures have been due to broken bonds, caused by joint working.

COMPANY 24.—Brazed bonds are often too short and break when the joints become low or slightly loose. Compressed-type concealed bonds: (1) Due to loose joint; (2) splice plate binding bond; (3) poor installation, not having bond terminal bright and not compressing terminal enough or too much.

COMPANY 28.—We have found that the principal cause of failure on all bonds other than the brazed has been on account of poor contact. With the brazed bonds, however, the contact remains perfect and failure only occurs when the bond breaks.

COMPANY 30.—Soldered bonds crack off from contraction of rail or from weather conditions. Stranded compressed-terminal bonds pinch and break at the end of the rail.

COMPANY 39.—The most prevalent cause of failure of concealed bonds is breaking of strands due to excessive vibration. Some other causes are: (1) Terminals broken by hammer blow of repair man; (2) strands broken by being squeezed by splice bar; (3) strands burned by accidental short-circuit of third rail; (4) strands broken by replacing of bolts in splice bars. In exposed bonds failures have been very rare and are included in (1) and (3) of above causes.

COMPANY 40.—(*a*) We find that the solder bonds fail due to the fact it is hard for even an experienced operator to obtain uniform results in installing. After installation, the action of the current seems to crystallize and deteriorate the solder, causing the terminals to drop off. The mechanical union between the bond and the rail is not of sufficient strength so as to prevent bonds being knocked off with a hammer and stolen. The strands break, of course, on loose joints.

(*b*) Pin-terminal bonds fail due to the corrosion of the terminals and the loosening of the same and strands breaking on loose joints. We believe that the corroding of the terminals is hastened in a new installation due to the fact that it is almost impossible to drill holes in the rail of an absolutely uniform size. This is also hastened by the unequal coefficient of expansion of the copper and steel during temperature changes.

(*c*) Electric-weld bonds fail by strands breaking on loose joints. We have had very few failures due to poor workmanship, and have had no terminals depreciate or drop off when properly installed.

COMPANY 41.—It has been our experience during the six years of service on this property that, with the use of the compressed-terminal concealed bonds, drilling the holes in the web of the rail, making a total of four holes in the end of each rail, weakens the rail at this point to such an extent that any undue strain brought to bear on this point will cause the rail to break. Have had eight breaks in the six years, and with the exception of two have always found the fracture followed down through one of the bond holes.

(*n*) QUESTION 18. RESISTANCE OF BONDS, NEW AND OLD.—Information on this point is somewhat meager and inconsistent. Only a few companies were able to give figures, and these are quoted below:

COMPANY 7.—A new twin-terminal bond will equal about 3 feet of rail, when the old ones will average about 4½ or 5 feet.

COMPANY 8.—The average resistance in terms of rail length for the different types of bond joints is rather an indefinite figure, due to the number of variables that enter into same. A joint newly bonded with a 4/0 bond will have a resistance equivalent to approximately 3 to 6 feet of adjoining rail, depending on the size of the rail. In about two years this will increase to about 5 to 8 feet, remaining constant at that amount for about six or eight years, when its resistance increases rapidly.

COMPANY 11.—With reference to twin-terminal and compressed-terminal bonds, we have found no difference in resistance between old and new bonding, so long as the bonds remain unbroken and their terminal contacts are unimpaired.

COMPANY 14.—The average resistance of new compressed-terminal bond is about 6 feet of rail. The average resistance of an old compressed bond is about 13 feet of rail. The resistance of brazed bonds after being installed five years is about 5 feet of rail.

COMPANY 16.—Our experience has been that there is very little change in the resistance of a bond if properly installed. As an example will give the results of a test made within the last 10 days.

The piece of track on which the test was made was constructed in 1907. Weight of rail, 85 pounds; car service, 10-minute intervals; construction, concrete ballast with subballast of crushed rock; average current per rail, 300 to 400 amperes.

The results of the test show the drop in millivolts on 24 joints, including 3 feet of rail, as compared to the drop on the 3 feet of adjacent rail. The figures range from 10 to 15 for the solid rail and from 10 to 18 for the joint. The average resistance of the 24 joints is about 10 per cent greater than that of 3 feet of solid rail.

The joints are bonded with two 400 000 cir. mils bonds per joint. The copper equivalent of these rails is about 850 000 cir. mils. We do not have on record the

readings on the joints when new, but considering the amount of copper in the joint and the copper equivalent of the rail we do not believe the resistance of the bonds could have changed but very little during seven years of service.

Our experience in compressed-terminal bonding indicates that the essentials for good results are to have the holes drilled of uniform diameter, free from all traces of any lubricant, bond terminals machine finished, in order to assure a driving fit; finally, the maximum amount of compression possible with tools available for this class of work.

COMPANY 19.—We consider that two 4/0 compressed-terminal bonds with a continuous rail joint has the equivalent resistance of 4 feet of 70-pound rail when new. Age does not affect this if the track joint is kept in good condition.

COMPANY 26.—Tests of compressed-terminal bonds and twin-terminal bonds are practically the same, 4 to 4½ new, 5 to 6 when old.

COMPANY 34.—Two 36-inch 4/0 bonds, pin-terminal, on 60-pound T rail, when new resistance equals 8 feet of rail. When in six years, resistance equals 10 to 12 feet of rail. Compressed terminals show about the same resistance.

COMPANY 35.—Average resistance of pin-terminal bonds on track rail equals 18 to 20 inches new, 36 to 40 inches old.

COMPANY 37.—In the use of brazed bonds there is a remarkable similarity between the resistance of the bond when first applied and when old, which indicates the great advantage of this type of bond over all others.

COMPANY 40.—(*a*) The 9-inch 300 000 c. m. soldered bond when first installed on 70-pound rail equals 8 feet of rail. We lose about 5 per cent of the bonds during the first year, and about 20 per cent the second year.

(*b*) The 10-inch 4/0 pin terminal when first installed on 85-pound tee rail equals 7½ feet of rail. The same bonds are equal to 9½ feet of rail at the end of first year, about 10½ feet of rail at end of third year, while at the end of four years we have found 40 per cent of the bonds out of the rail.

(*c*) The short 4/0 electric-weld bonds are equal to 4.9 feet of rail when first installed and have shown no terminal depreciation during our 11 years of use.

3. COMPILATION OF DATA SUBMITTED BY OPERATING COMPANIES ON WELDED AND OTHER TYPES OF RAIL JOINTS

Of the 42 companies enumerated heretofore but 17 employ other than bolted joints, and the data submitted by these roads apply for the most part to old types of welds which are now either practically obsolete or which have recently been so modified and improved that records of failures during the past years are unreliable and misleading as an indication of the performance of modern welded joints. Unfortunately, but few of the larger traction companies whose experience would be most valuable on this subject are included in the list of those answering our circular, and while many of these have been visited and interviewed regarding their experience with rail joints, very little in the way of statistics from them is at hand for tabulation.

It is obviously unwise to generalize or base conclusions and percentages on data compiled from so few as 17 reports, representing as they do but a small percentage of the total mileage equipped with welded joints. The tabulations and quotations which follow, therefore, should be considered as representing special rather than average conditions. They will, however, be used in a later part of the report in connection with material obtained from other sources as the basis for some general conclusions and recommendations.

(*a*) QUESTION 1. *Number of joints in use.*—Table 6 gives the total number of welded as well as bolted joints reported by the several companies answering, as well as the number of companies reporting the use of each type of joint.

As with the bonds, only a fraction of the total number of joints represented have been reported, owing apparently to the lack of records. The questions on welded and other types of joints were intended to cover only electrically continuous joints. Nine companies, however, gave figures on bolted joints as well, which accounts for the comparatively small number reported.

TABLE 5

Number of Rail Joints Reported

	Number in use	Companies reporting use		Number in use	Companies reporting use
Electrically continuous joints:			**Bolted joints—Continued.**		
Cast welds	149 716	10	Bonanza joints	.....	3
Thermite welds	46 849	7	Duquesne joints	2 147	3
Electric welds	11 697	5	Bonanzo and Duquesne	20 000	.....
Arc welds	1 300	4	Atlas	.....	2
Clark joint	50 000	2	100 per cent joints	2 000	1
Nichols joint	8 490	1	Angle bars	159 402	.....
			Channel bars	32 671	.....
Total	268 052	.....	Fish plates	9 336	.....
Bolted joints:			Total	301 925	.....
Continuous joints	68 669	19			
Weber joints	7 700	3			

(*b*) QUESTION 2. TYPES OF CONSTRUCTION.—With but few exceptions welded joints have been installed only in city paved streets with concrete or stone ballast. A few companies report the use of welded joints in macadam or earth streets and one on open track.

(*c*) QUESTION 3. ELECTRICAL EFFICIENCY OF JOINTS.—Ten companies reported the efficiencies of their welded joints to be 100 per cent or better. One company gave the efficiency of cast welds to be 67 per cent. Six companies had no data on this question. The electrically-welded joint was reported by various companies from 100 per cent to 170 per cent efficient, electrically.

(*d*) QUESTIONS 4 AND 6. LIFE OF JOINTS AND CAUSES OF FAILURE.—The following quotations, taken from answers to questions 4 and 6, are given in preference to a summary which would not be satisfactory:

COMPANY 3.—Our experience shows that the life of our rail on good track is from 15 to 20 years under our ordinary traffic conditions, say one 20-ton car every 3 or 4 minutes per 18 hours. On this type of track 95 per cent of our 5000 cast-welded joints have lasted the entire life of the rail. The electrically welded joints have been in only two years. We shall be disappointed if 95 per cent do not last the life of the rail.

Where the continuous rail joint has been applied we had no renewals for the first two years. From the third to the fifth year about 20 per cent of the joints required renewal. At the end of 10 years the renewal was total; that is, all of the joints had been renewed. With ordinary splices under the same traffic conditions as those under which the continuous joints were used, all of the splices had to be renewed within five years.

The above is an opinion in the absence of absolute data, but is in a general way correct.

The usual cause of failure in every joint is the deflection of the joint due to the load, causing an ultimate pounding of the joint. The final result is a cupped place on the receiving rail and looseness due to wear, the wear being on the fishing surface of both the rail and the splice. This is true for every type of joint.

When rail is first welded either electrically or by means of cast weld about 1 per cent of breaks will occur within the first 60 days. We expect such breaks and consider them necessary to permit the rail to adjust itself to conditions, and the repair of these breaks should be included in the cost of the first installation of the welded joint.

COMPANY 4.—The average number of cast-weld joints replaced in repairs each year is about 1000, the total number of joints in service being about 42 000. A great number of joints were taken out when tracks were replaced in 1913 and 1914 where the joints were originally installed in about 1895, thereby indicating that the majority of the joints will last as long as the rail, the failure being due to the rail itself and not to the joints.

The most prevalent cause of failure in the cast-weld joint is the loosening up of the rail in the joint.

COMPANY 11.—Riveted and thermite-welded joints (Clark joints) have been in use but three years. So far we have had no failures and no defective joints where applied to new rail. Every indication points to a life of this type of joint equal to the life of the rail.

Lorain electrically welded joints have shown but from 1 to 5 per cent, or more failures per annum, depending upon the condition of the rails.

Bolted joints will in no case last as long as the rail.

Our experience with cast-welded joints has been more satisfactory than with bolted joints. The percentage of failures is not as great as in electrically welded joints.

Electrically welded and cast-welded joints have nearly all been applied to partly worn track; therefore our experience is probably not a fair guide to similar joints applied to new track.

In electrically welded joints the failures are due to many causes, principally the breaking of the rail at the ends of the welding bars, splitting of the web above the bars and the depression of the head due to nonsupport.

Cast-welded joint failures are due to depressed or cupped heads and split webs. There are very few cases where joints show any true welding.

COMPANY 16.—In the 100 thermite joints there have been four breaks in four years of service. The rest show serious mechanical wear which will soon require extensive repairs or replacement. The life of other types of joints varies with service and the care taken of the track. Under our average conditions a continuous type of joint should last from 12 to 15 years. We have no definite data in this respect, as this type of joint has not been in use long enough to require replacing.

The thermite-welded joints have failed by breaking due to contraction of rail. They also show very rapid mechanical wear, due to the soft material in the weld. This latter cause of failure has largely been removed by recent improvements.

COMPANY 17.—The most prevalent cause of failure of a mechanical bolted joint in our case has been due to not drawing the rails together as tightly as possible before finally bolting on the joint and the irregularities in the rolling of the rails.

The few welded joints we had have not given satisfaction, to some extent on account of being used on old track. We have never had any on new steel.

COMPANY 18.—In regard to cast-welded joints would say that they have given good service for 15 years and taken as a whole I consider that they have been a success. Of course there have been some failures and in the 15 years a great many mechanical joints have been substituted for the welded joints, but I judge that this has not amounted to more than 10 per cent, and would possibly be as low as 5 per cent of the total number. After 13 to 15 years service these joints are still failing at the rate of probably 1 per cent or 2 per cent per year, and of course the failures in previous years have been less than that amount.

In regard to mechanical joints I believe that a very much larger per cent of these have failed or required repairs. What the percentage is no man can tell. A large percentage of those failures I attribute to the fact that a great many of the mechanical joints were not put on with care that should have been exercised, nor with proper material used in the bolts. Recent experience would indicate that mechanical joints when properly applied could be made to hold with as small percentage of failures as can be obtained with welded joints.

The joints made with the thermite welds have been used only on compromise joints. The percentage of failures of these has been negligible.

No attempt has been made to replace welded joints which have failed. In cases of that kind we have always substituted mechanical joints.

COMPANY 19.—The life of a joint nowadays will in most cases equal that of the rail. And while the joint may "pound" within five or six years, depending on the nature of the traffic, they can be built up and smoothed off with electric welders and grinders so that the joint can be maintained as long as the rail itself.

The most prevalent cause of failure is the giving away of the track foundation owing to water leaks saturating the soil under the track foundation.

COMPANY 22.—Failure on 1600 thermite welds, late type, not over 1 per cent per annum, no exact record, however.

On 800 arc welds no failures to date where joints were properly welded.

COMPANY 27.—The failures of cast-welded joints per year is less than three-fourths of 1 per cent of the total number of joints in use.

The usual cause of failure on cast-welded joints results from either imperfect weld or from excessive pounding at the joint due to imperfect surfacing or wear.

COMPANY 32.—Cast welds: The castings crack, the rails pull out of the castings, or the receiving rail wears out due to the softening of the rail by the welding heat. The latter is the most prevalent cause of failures.

Channel-bar joints and angle-bar joints: Loose bolts are probably the cause of the greatest number of failures in these joints. If these joints are not properly fitted to the rail or bolts are not kept tight, the plate is bent or deformed under the rail head on the receiving side of the joint.

Nichol's composite joint: No failures have occurred since these joints were installed three years ago.

COMPANY 34.—The 8 miles of electrically welded joints were installed in 1906 and are in good condition at present. Only seven joints have broken.

This is on suburban road with expansion joints every 1000 feet.

COMPANY 37.—Have had but three failures on 50 000 Clark joints, standard since 1906.

(*e*) QUESTION 5. COST OF JOINTS.—The following cost data are, in some instances, of little significance, as they are given without information as to weight of rail or as to whether the cost includes the bonding of the mechanical joint or the renewal of pavement. They are tabulated under the various types of joints for which costs were given and include both labor and material.

CAST WELD

Company	Rail	Cost
3	7-inch and 9-inch rail	$5.50
4	6-inch and 7-inch rail	3.75
18		3.50
19	109-pound and 107-pound girder rail	3.14
25	62-pound T rail	4.87
25	70-pound rail	4.87
26	56-pound, 85-pound, and 91-pound rail	8.00

CAST WELD—Continued

Company	Rail	Cost
25	70-pound rail	$5.24
27	91-pound T rail	4.00
29	60-pound and 70-pound rail	5.50
32	9-inch rail	3.00
32	7-inch rail	2.60
32	6-inch rail	2.50
32	95-pound T rail	2.70
	Average cost	4.30

THERMITE WELD

16	9-pound to 125-pound girder rail	$7.00
18		7.50
22	80-pound girder rail	5.00
22	70-pound, 7-inch girder rail	6.00
25	70-pound rail	4.43
29	Old type on 60-pound to 116-pound girder rail	4.00
	Average cost	5.65

ELECTRIC WELD

3	contract price	$5.50
25	60-pound to 106-pound rail do	6.25
29	116-pound girder rail do	7.00
	Average cost	6.25

ARC WELD

22		$6.23
24	Using old angle bars	1.50
25		4.35

CLARK JOINT

37		$4.60–$5.00

NICHOL'S COMPOSITE JOINT

32	9-inch rail	$8.50
32	7-inch rail	7.75
32	100-pound T rail	7.00

CONTINUOUS JOINT

Company	Rail	Cost
3	7-inch	$4.00
3	9-inch	5.00
16	7-inch and 9-inch	6.00
17	Paved streets	4.80
17	Open track	1.65
18	12-hole plate, including bond	6.25
23	7-inch T rail	2.50
24	Including two 4/0 bonds	5.65
26	40-pound, 56-pound, and 60-pound T	1.75
26	70-pound T	2.10
26	72-pound T	3.05
26	80-pound high T	3.80
29	116-pound, 7-inch girder rail	4.75

DUQUESNE JOINT

32	80-pound T rail	$2.10

100% JOINT

30	70-pound T rail	$2.00

ANGLE BARS

3	70-pound rail	$2.10
3	7-inch rail	2.50
3	9-inch rail	3.00
23	4-hole plates on 91-pound, 7-inch girder rail	1.50
26	35-pound T rail	1.00
26	40-pound T rail	1.10
26	56-pound T rail	1.25
26	60-pound T rail	1.50
26	72-pound low T	2.50
26	80-pound low T	2.80
32	9-inch rail	3.00
32	7-inch rail	2.25
32	100-pound T rail	2.20
32	80-pound T rail	1.50
32	60-pound T rail	1.30
32	40-pound T rail	1.00

(*f*) QUESTION 7. TEMPERATURE VARIATION IN WELDED JOINTS.—The tabulated answers to this question as given in the following statement are no doubt largely based upon guesses or estimates. In no case is it stated that they are taken from experimental observations.

COMPANY 3.—All welded joints are in paved streets where the rail and track is gripped and firmly held by the pavement. The temperature of a rail buried in most pavement in the summer time rarely exceeds 60° average temperature in our climate. Also the rail buried as above seldom goes below 30°, no matter how cold the atmospheric temperature is. The maximum temperature variation of a buried rail in our climate is probably not greater than 40°.

COMPANY 4.—Eighty degrees F to 15° F.

COMPANY 10.—Ninety degrees F to 10° F.

COMPANY 11.—Ninety degrees F to 25° F. The rail never gets as cold or as hot as the air temperature.

COMPANY 16.—The maximum change in temperature of atmosphere is about 100°. The welded joints, being embedded in concrete, are subjected to a considerably less range, probably not over 50°.

COMPANY 24.—Air temperature 0° to 100° F; ground temperature 30° to 70° plus or minus.

COMPANY 25.—Sixty degrees F maximum range.

COMPANY 26.—Ninety degrees F to 20° F.

COMPANY 28.—Fifty-four degrees maximum range.

COMPANY 30.—Seventy-five degrees F maximum range.

(*g*) QUESTION 8. EXPANSION JOINTS.—Eight of the 17 companies use no expansion joints whatever. Those that do are quoted below.

COMPANY 17.—Special expansion joints of a modified slotted angle bar type are used on bridges and viaducts and we also use slotted angle bars in open track at intervals.

COMPANY 22.—On all lines we leave a joint about every 500 feet, which joint is connected by the usual angle bars and bolts. Our experience is, however, that these joints do not move any more than the welded ones, the friction of the pavement holding the rail rigid. On one line 7½ blocks long we installed expansion joints with slotted bolt holes. This line is partly planked and partly dirt filled to the top of the rail, and though most of the joints have broken none of the expansion joints have moved.

COMPANY 23.—With welded joints we use continuous plates every 500 feet and at special work.

COMPANY 25.—Approximately every 400 feet continuous bonded joint. We are not welding any open track.

COMPANY 34.—Expansion joints in the electrically welded track are placed 1000 feet apart. In other track none, except on open track, where ⅛ inch to ⅜ inch is allowed, depending on temperature when laid.

COMPANY 37.—Do not use expansion joints on regular work. Only expansion joints we have are on long viaducts, where rail is fastened directly to bridge members.

IV. ANALYSIS OF DATA

1. THE MECHANICAL JOINT

That the problem of rail-bond maintenance is largely that of joint maintenance and becomes serious only where loose rail joints exist is attested by a large majority of the operating companies

enumerated in Section II of this paper as well as by the verbal testimony of the engineers of a number of other companies. It is apparent, therefore, that the first step in an attempt to reduce the present high percentage of bond failures should be toward bettering the condition of the bolted joint.

The principal causes of failure of the ordinary bolted joint have been frequently discussed and are more or less familiar to the majority of electric railway engineers, and will here be reviewed only briefly.

(*a*) DEFECTIVE ROADBED.—This includes poor ballast, poor drainage, water leaks, and decayed ties. While these defects are external to the joint proper, they nevertheless exist and will tend to the ultimate failure of the best of bolted joints.

(*b*) NONUNIFORMITY OF RAIL SECTIONS.—No two rail sections will be found to be absolutely identical. The difference will vary from an inappreciable minimum to the maximum allowed in the specifications adopted by the American Society for Testing Materials. These inequalities are the result of wear of rolls and different degrees of shrinkage with cooling. When two unequal rail sections are joined together by uniform splice bars it is evident, therefore, that the bars do not fit with equal closeness the fishing surfaces of the two rails at the joint. With the passage of the wheel over such a joint one rail will be depressed below the other and pounding of the joint will result, particularly if the receiving rail is the lower of the two. Continual pounding of a joint eventually develops a cup in the receiving rail and rapid depreciation follows if the joint is not given proper attention

(*c*) DEFECTIVE RAIL ENDS.—Rails rolled some years ago by some of the steel companies had a distinct dip of the head at both ends. When joined together a depression or cup was left at each joint which, if allowed to remain, resulted in further wear and early failure of the joint. An order of rails received in Worcester, Mass., at one time was so defective in this respect that both ends of all rails had to be sawed off before they were installed. While this condition has not been met with in recent years it has no doubt been the cause of a number of joint failures in the past.

(*d*) FAILURE TO GRIND JOINTS.—Slight inequalities exist in rail heads as well as in the fishing surfaces, so that on newly bolted

joints a difference in elevation of the abutting rails often exists and unless filed or ground down to a perfect surface alignment will soon develop pounding and cupping. A number of companies now make a practice of running over all newly bolted joints with a track grinder and find that the slight expense is well justified by the increased smoothness and resulting longer life of the joints.

(*e*) Loose Bolts.—This is by far the most universal and prevalent cause of complaint in connection with joint failures and has been the source of constant annoyance and expense to practically every electric railway in the country. Bolts become loose through various causes. They are stretched beyond their elastic limit when being tightened and are thereafter unable to accommodate themselves to expansion and contraction incident to temperature changes and to the vibrations from traffic. As soon as the tension on the bolts is thus relieved the joint begins to work, which allows the plates to wear and further augments the pounding and cupping. It is practically impossible to permanently install joint plates before traffic is put on the track. Slight inequalities in plates and rails permit their intimate contact only at points, and until these high places are worn off or flattened by several days' traffic a proper seating of the plates is difficult. A number of operating companies now follow up all bolted joint installations and take up the slack in the bolts which has developed with a few days' traffic. This practice is obviously commendable and should be rigidly adhered to under all circumstances. The tightening of bolts on all exposed joints once each year or at other regular intervals is practiced by some companies with a corresponding increase in the average life of the joints.

(*f*) Improved Bolts.—Perhaps the most important improvement in the bolted rail joint in recent years and the one which will do more than any other thing to lengthen the life of the joint is the substitution of improved bolts for the more inferior grades. Within the last few years bolts having a high elastic limit as well as a great ultimate strength have been put on the market by several manufacturing companies and are now coming into general use both for special work and straight track.

A large number of companies was consulted regarding the properties and effectiveness of these bolts, and, while a number of

them stated that trial orders had been placed for a limited number or that they were experimenting with them and believed them far superior to the old bolts, practically no one was in a position to give positive testimony based on observations covering any great length of time. One notable exception to this was found with the Harrisburg Railway Co., which was using improved bolts on a steam railroad crossing where endless trouble had been experienced with ordinary bolts, including various patent washers and lock nuts. After the installation of the improved bolts no trouble was experienced and though no lock nuts or other precautions have been employed to keep the nuts tight they have shown no tendency to work loose since their installation.

In answer to question E–3–87, in the June publication of the A. E. R. A. for the year 1915, asking for information as to the economy of using special heat-treated bolts in the joints of railroad crossings and special work the following interesting replies are quoted:

A. E. Harvey, Chief Engineer Metropolitan Street Railway Co., Kansas City, Mo.—After a careful study of this question for several years the writer became convinced that one of the principal factors in the failure of mechanically applied joints was the poor quality of material used in bolts which failed in time, not through the stripping of threads or breaking, but through a gradual stretching and loosening. Over a year ago the use of the high-grade steel bolt with an elastic limit of 75 000 pounds was begun, and they have given excellent satisfaction. The high elastic limit permits of the stretching of the bolt, to some extent, without its receiving a permanent set, thus tending to keep the nut tight. Bolts for this work need not necessarily be material of alloyed steel or heat treated. There are a number of concerns that now manufacture bolts of high-grade steel with an oil finish that answer every purpose in track work and that at a very slight cost above that of the ordinary track bolt. The above applies not only to the use of bolts in special work and railroad crossings but in all track work.

A. V. Brown, Engineer Maintenance of Way Lake Shore Electric Railway Co., Sandusky, Ohio.—Have had excellent success with heat-treated bolts at crossing frogs and are now specifying them on all crossings.

H. A. Clarke, General Manager Ithaca Traction Corporation, Ithaca, N. Y.—I would advise that I have not made use of special heat-treated bolts for such purposes but have used special steel-alloy bolts, having a very high tensile strength, and we find that it is economical. The breaking of such bolts is diminished at least 50 per cent, and in addition the crossings and special work are held more rigidly, decreasing the wear on the joints. We have also found it economical to use special alloy-steel bolts of high tensile strength for ordinary joints. We have found a great many of the ordinary track joints becoming loose, due to the stretch of ordinary bolts. This is almost entirely overcome by the use of special alloy bolts.

J. B. Tinnon, Engineer Maintenance of Way Chicago & Joliet Electric Railway Co., Joliet, Ill.—The first cost of heat-treated bolts is about twice that of ordinary bolts, but the fact that they no not stretch as easily will alone save their extra cost, because they will not require tightening as frequently. Heat-treated bolts are also much tougher than ordinary bolts and are therefore not so easily broken by sudden shocks; in fact, they have to be cut about two-thirds through before they will finally break off. Since the stretching of the bolt is the cause of most loose and broken bolts, the advantage of a tougher bolt that will not readily stretch is very obvious.

George H. Pegram, Chief Engineer Interborough Rapid Transit Co., New York, N. Y.—Our experience does not justify me in specifying special heat-treated bolts. Our specifications, however, require a bolt of high tensile strength with a severe bending test, which requires a high quality of steel.

This testimony in favor of bolts having a high elastic limit as against iron or even carbon-steel bolts is apparently conclusive, and the slight additional expense is completely justified by the decreased maintenance and additional life of the bonds and joints, to say nothing of the improved riding properties of the roadbed.

(*g*) Joint Plates.—The character of joint plates affects the life of rail bonds in so far as they have to do with the general condition of the joint with respect to deflection and vibrations and also as they tend to restrict the natural vibrations and movements of concealed bonds.

(*h*) Room for Concealed Bonds.—A concealed bond, i. e., one installed under the joint plate, is ordinarily subjected to two kinds of vibrations. It is bent or deflected by the deflection of the joint under the car wheel, and it is lengthened and shortened by the diurnal expansion and contraction of the rails on exposed and other joints where such expansion and contraction takes place. Concealed bonds are designed to accommodate themselves to these motions and do so admirably when not restricted in their natural movements by the action of the plates or bolts.

The vibrations and bending of bonds incident to the vertical motion of the joint and rail end is supposed to be taken care of by making the bond long enough to withstand such vibrations, while the longitudinal motion resulting from expansion and contraction is taken up by the crimp which is put in all concealed bonds. The ability of a bond to withstand vibrations depends largely upon its length. This relation has been made the subject of experimental investigation by the American Steel & Wire Co. and other manufacturers of bonds. A vibration testing machine

designed to approximate the motions of a very loose rail joint grips the bond terminals and gives them alternate vertical displacements of any desired amount. With every 125 vertical oscillations the bond is lengthened and shortened once through any required distance. The following figures are given as results of tests on bonds of various length: 7-inch bond began breaking at 41 000 vibrations; 8-inch bond began breaking at 215 000 vibrations; 10-inch bond began breaking at 1 279 000 vibrations; 14-inch bond began breaking at 7 887 000 vibrations.

This test gives no indication of the life of a bond on a good joint but represents extremely poor track conditions. Converting these figures into years of life on a track carrying double-truck cars under a six-minute headway we find that the 10-inch bond will not begin to fail for five years and the 14-inch bond will remain intact for approximately 30 years. That such performances are never realized in practice on bad joints and seldom on perfect ones requires no argument.

Without a doubt the chief difference between the laboratory life test and performance under service conditions lies in the fact that in the latter case the full length of the bond is seldom if ever utilized, but is restricted by the squeezing action of the plates, or the crowding action of the bolts, and in double bonding sometimes by the protruding button of the bond on the opposite side.

The ordinary splice bar, such as is used on steam roads and which was the only type of joint plate available in the early days of electric railways, makes no provision for the accommodation of the concealed types of bonds and no end of difficulty has been experienced by all operating companies on this score, particularly with the smaller rail sections. There is general complaint that the steel companies have been slow in rolling plates specially designed to meet this problem and numerous companies, in their earlier installations, resorting to the only available material, applied concealed bonds under plates which did not permit of their free movement and thereby led to their early failure.

Fig. 13 shows how the bolts and Fig. 14 how the button of the bond on the opposite side might easily prevent any movement of the bond between these points and the bond terminal, particularly under plates which have not been designed to take care of this feature.

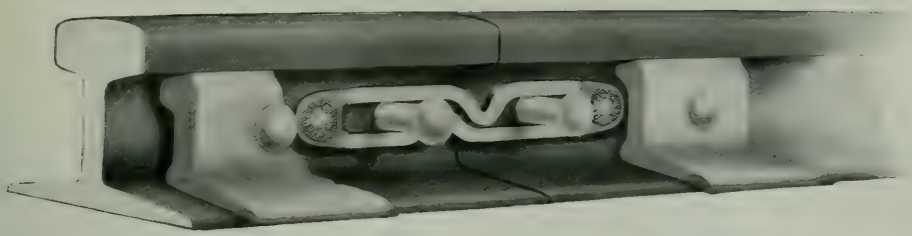

FIG. 13.—*Showing interference of bolts with movement of bond*

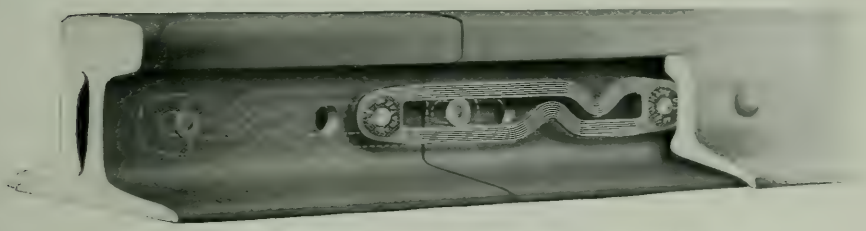

FIG. 14.—*Showing interference of bond terminal in double bonding*

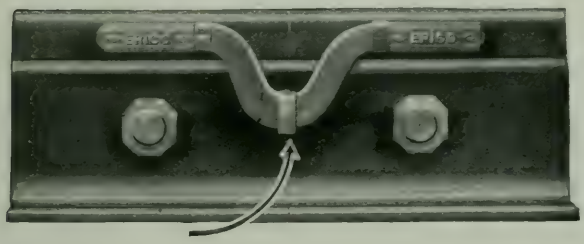

FIG. 17.—*Clip to prevent separation of ribbons*

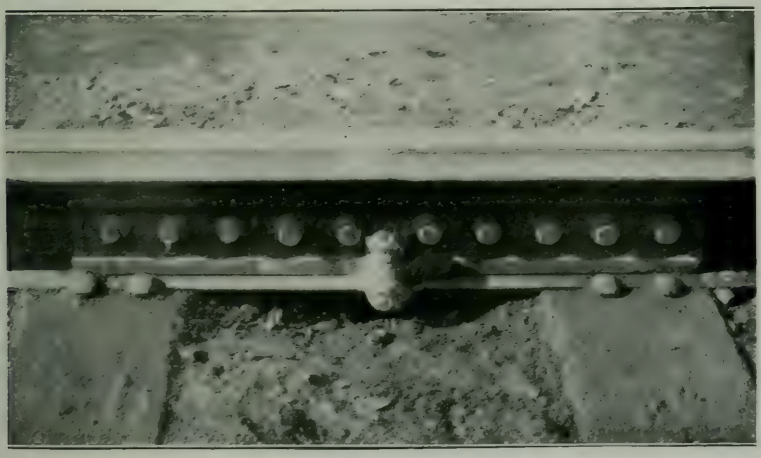

FIG. 22.—*Completed Clark joint*

On badly worn and loose joints of the type shown in Fig. 13 the entire vertical motion of the bond is confined to the short region between the bolts nearest the rail ends and in bonds which are hugged tightly by the plates to a still more restricted length. Such a condition results in the breaking of the strands, not at the bond terminals, as would happen with no restrictions, but at the juncture of the rails or near thereto. Even upon well-maintained joints in which there is practically no vertical motion the continual lengthening and shortening of the bond resulting from expansion and contraction, and which is confined to a comparatively short length, will produce the same effect. Such failures have been more prevalent on open track, where rails experience the full effect of temperature variations, than in city streets. This may be partially the result of better ballast and heavier rails in the latter type of construction, but it is quite reasonable to suppose that the linear expansion and contraction which takes place on the open track is largely responsible for the crystallization and breaking of the strands and ribbons.

(*i*) Examples of Bond Failures.—Companies 2 and 14 specifically state that expansion and contraction in rail joints is responsible for bond failures, and Company 16 says that the failure of concealed bonds is confined to those joints in which expansion and contraction of the rails takes place in the joint. The Boston & Worcester Street Railway Co. presents a striking example of this type of bond failure on their suburban line between Boston and Worcester. It is reported that only a small per cent of the original 12-inch concealed-wire bonds are now in service, a large majority of them having failed by the wires breaking in the middle near the juncture of the two rails.

Engineers of the American Railways Co., which operates a number of properties, state that they have had difficulty in obtaining room for concealed bonds on rails of 60 pounds per yard and smaller. On large rails they report ample room and state that they will permit of very loose joints without breaking bonds, while the slightest motion in the joints of the smaller rail sections will quickly result in broken strands or ribbons.

Some of the bond manufacturers have attempted to meet this problem by providing the operating companies with stranded

bonds having a triangular section. A sectional view of such a bond installed is shown in Fig. 15. While this may be an improvement over a bond having a circular section, its very necessity is an acknowledgment of a condition which requires a more drastic remedy.

(*j*) SPECIAL PLATES.—Some of the larger and more progressive companies have called on the steel manufacturers to roll special plates for them which have been designed to give room for concealed bonds. This has been done in some cases and in a few instances such plates have become standard with the manufacturers. This is particularly true with respect to the manufacturers of some of the patent joint plates, such as the continuous joint and the Bonzano joint. Fig, 16 shows a sectional view of continuous joint plates applied to a 40-pound rail. It is seen that ample room is provided for concealed bonds. The joint plates recently adopted as standard by the Amerian Electric Railway Association were designed to give ample clearance for bonds and are now being rolled. These standards, however, were adopted for only the 7-inch and 9-inch rails, on which the problem of bonding was not so difficult as on the smaller sections.

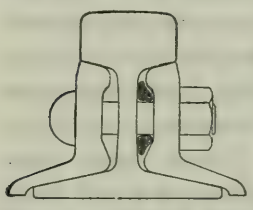

FIG. 15.—*Standard joint plates, showing inadequate space for bond*

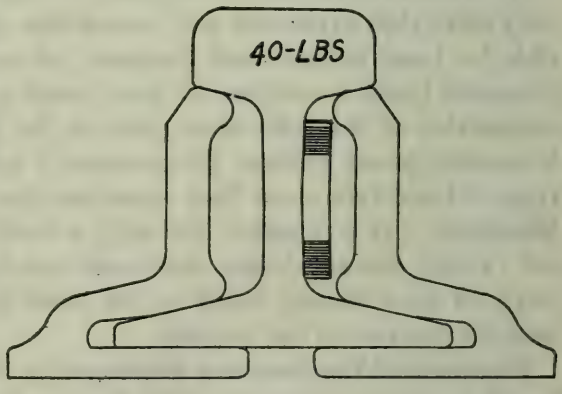

FIG. 16.—*Special plates, showing ample provision for bond*

(*k*) IMPROVED JOINT PLATES.—Not only do some of the improved joint plates materially increase the life of concealed bonds by giving ample clearance for them, but their ability to better support and maintain the joint than the old types of plates is sufficient justification for their use. Among the improved bolted joints the continuous joint seems to be the most popular with the operating companies. Figures submitted in Table 6 show that 19 companies reported the use of this type of joint, whereas the largest number using any other

type of improved plates is 3. The total number of continuous joints reported is 68 669, which is more than twice the number of all other types of improved joints reported.

This type of joint plate when properly installed with bolts having a high elastic limit grips the rail so firmly that expansion and contraction within the joint is largely eliminated, particularly on city tracks. We quote Company 3 with reference to this point:

> We think if the bolts in continuous joints are drawn tight there is very seldom any slipping of the joint, due to expansion or contraction, as this joint grips the rail very firmly, so that a well-bolted continuous joint gives nearly the same effect as welding.

The type of bolted joint referred to under "Mechanical joints" in Section II of this paper, wherein a shop fit is obtained by reaming holes and using machine bolts and in which no expansion and contraction is allowed, has, to our knowledge, not been used on open track, although welded joints have been used in a number of installations for this purpose, expansion and contraction being taken care of by expansion joints at regular intervals of about 500 to 1000 feet. If such improved bolted joints were used on open track in connection with expansion joints, a great reduction in the maintenance cost of both bond and joint would be affected, to say nothing of the economy of operation and improved operating conditions generally. The ultimate economy of such construction would have to be carefully considered for any given project, but that it would be fully justified on heavy traction lines is firmly believed. If installed according to the best modern practice, bond failures would be reduced to a minimum, being relieved of the continued lengthening and shortening so prevalent in the ordinary joint. Maintenance would consist of occasionally going over the joints and tightening the bolts. If in time the rail ends began to cup, they could be inexpensively built up by applying new metal with the arc welder or acetylene flame and then ground to a true surface alignment. Such joints with the comparatively slight maintenance here mentioned would undoubtedly have a useful life equal to that of the rail and at the same time provide a continuous and permanent return circuit for the electric current. We believe the type of construction here described to be not only practicable but of ultimate economy, and urge its adoption by the operating companies at least on an experimental basis.

2. TYPES OF BONDS AND FEATURES OF INSTALLATION

(*a*) COMPARISON OF COMPRESSED AND PIN TERMINAL BONDS.—Stud-terminal bonds according to our definition on page 12 include both compressed-terminal and pin-terminal bonds, and each of these types comprise ribbon and wire bonds for both concealed and exposed application.

The tabulation on page 29 shows that 929 600 compressed-terminal bonds were reported as against 362 800 of the pin-terminal type. These figures, together with a majority of testimony as to preference, indicate that the compressed terminal is easily the favorite among a majority of the operating companies. On the other hand, however, must be considered the fact that the pin-terminal bond has been adopted as standard and is being employed with phenomenal success by a number of the largest operating companies, including the New York Central & Hudson River Railroad Co. and the Pennsylvania Railroad. While it is not possible to say in general that one of these types is better or worse than the other it is hoped that a careful analysis of all information available will aid in reconciling the differences in opinions regarding these two types, and establish the fact that each type has characteristics and properties which makes it peculiarly adaptable for certain classes of work or under certain special conditions.

One of the arguments put forward in favor of the compressed-terminal bond is as follows: The contact resistance between copper and steel decreases as the pressure increases up to about 30 000 to 40 000 pounds per square inch. As copper reaches its elastic limit and begins to flow at about 20 000 pounds per square inch, the minimum contact resistance is not reached with the pin-terminal bond since the copper is not confined during the driving of the pin, but is free to flow out around the pin, forming a button on the opposite side of the rail as is illustrated in Fig. 3. With the compressed-terminal bond, it is argued, the copper is confined between the terminals of the compressor, and not being able to escape is subjected to a pressure limited only by the design of the compressor or the diligence of the workmen.

This argument, which at first may appear to be tenable, is undoubtedly fallacious. It is true that very soft and thoroughly

annealed copper has an elastic limit of about 20 000 pounds per square inch, but upon undergoing a very small amount of manipulation it rises rapidly to from two to three times this value. As the action of the compressor or even the driving of the expanding mandrel produces a distortion in the copper more than sufficient to bring about this change in the elastic limit it is obvious that the pressure required for minimum contact resistance is reached in both the compressed and pin terminal type of bonds.

If there is any difference in the contact resistance of these two types it appears to be so slight as to have practically no effect upon the total resistance of a bonded rail joint. The average of 32 tests on each type conducted by the Chicago Board of Supervising Engineers in 1911 shows the pin-terminal bond to have a conductivity of 96.65 per cent of that of the hydraulic-compressed bond and 98 per cent of that of the hand-compressed bond. As the double contact resistance of a 4/0, 10-inch, copper bond is only about 20 or 25 per cent of the total resistance of the bonded joint the slight difference in the contact resistance of the two types would affect the total resistance of the joint in the order of a fraction of 1 per cent, which is so small as to be entirely negligible for practical purposes.

The contact resistance of a stud-terminal bond when newly and properly installed is often quite a different thing from the resistance of the average bond after being subjected to several months or years of service. That the two may be quite different is evidenced by the greater part of the testimony recorded in answer to question 18, although several companies believe that bonds show little if any increase in resistance if the joints are properly maintained. The increase in the resistance of a joint in some instances may be solely the result of the loosening of the joint plates. Tests recently conducted by the Bureau of Standards, the results of which are given on page 119 of this paper, show that newly bonded and bolted joints have a much lower resistance with the plates on than with the plates removed, indicating that tightly bolted plates add very materially to the conductance of a rail joint. Also recent tests of joint resistances on unbonded tracks which have been in service for a number of years show

that only about 5 per cent of unbonded joints have a resistance less than 1000 feet of rail.

While these tests might in some cases account for the apparent increase in resistance of bonded joints, it is undoubtedly true that a large number of the mechanically applied bonds slowly increase in resistance and may or may not reach a stage, within the life of the joint, where corrosion becomes so serious as to require the replacement of the bond.

While contact deterioration has been attributed to the difference in the coefficients of expansion of copper and steel and to other uncontrollable causes, it is undoubtedly true that by far the most prevalent cause of such deterioration is natural and electrolytic corrosion resulting from the entrance of moisture between the two metals. Considerable evidence is at hand to show that, as a rule, on compressed-terminal bonds moisture finds admission to the bond terminal between the head of the bond and the steel on the bond side of the rail. Engineers of the American Railways Co. state that they have removed hundreds of compressed-terminal bonds after being in service for a time and that on nearly every one the corrosion had started on the shoulder of the terminal on the bond side of the rail.

Experiments conducted by bond manufacturers have demonstrated that, under the action of a compressor, a bond terminal will begin to expand at the end opposite the head of the bond, and will gradually fill the hole toward the head as the pressure is increased. It is evident, therefore, that such failures as those reported by the American Railways Co. are the result of incomplete compression and emphasize the necessity of careful attention to this feature.

The life of poorly compressed bonds is possibly lengthened by grinding or otherwise cleaning, at the time of installation, the web of the rail with which the bond terminal comes in contact. Company 10 reports that they have greatly increased the life of their compressed-terminal bonds by this operation and attribute it to the good contact between the head of the bond and the web of the rail, which they believe delays the entrance of the moisture to the terminal proper.

A few complaints have been registered against the pin-terminal bond on account of the steel pin being subject to corrosion when allowed to come in contact with the earth. It is claimed that corrosion of the steel pin takes place and rapidly rusts it out, thereby relieving the compression on the copper terminal.

The great advantages of the pin-terminal bond as claimed by the friends of that type are, first, that it can be installed with uniform and consistent results by ordinary labor, while the compressed-terminal type requires careful and expert labor for satisfactory results; and, second, it can be installed without interruption to traffic or the danger of a derailment, which is possible when using a compressor across the rail.

Regarding the first point there appears to be a division of opinion, some claiming that the compressed-terminal type is more nearly "fool proof" than the pin-terminal bond. It is claimed by advocates of the compressed type that the big New York companies, who are having such phenomenal success with the pin-terminal bond, were forced to the adoption of that type by company rules which forbid the use of a compressor or any other tool which might cause a derailment; and the rigid specifications and extreme refinements which they have adopted in connection with the purchase and application of their bonds inclines one to the conclusion that this, rather than the first-mentioned reason, was the determining factor in making their selection.

It is significant that the principal advocates of the pin-terminal bond are to be found among the larger operating companies. The Philadelphia Rapid Transit Co. and the Bay State Street Railway Co., both operating extensive systems, may be added to the list of New York companies already mentioned. The observations of J. B. Taylor, engineer of way for the Philadelphia Rapid Transit Co., may throw some light on this point.

Mr. Taylor states that in a system of the size of that in Philadelphia a number of repair jobs are usually in progress at the same time and it would not be practicable to have expert bonding men at every job at the proper time. When the rails are ready the bonds must be applied, and as pin-terminal bonds can be installed quickly and with a fair degree of uniformity by an ordinary trackman, they are found to be better suited for this

class of work than the compressed-terminal bond, which should not be installed by any but an experienced and careful workman.

The Bay State Street Railway Co. has a thousand miles of track in and around Boston. They adopted pin-terminal bonds five years ago because of the ease and uniformity with which they can be applied and for their "fool-proof" qualities. All bonds are purchased under rigid specifications based on their own drawings. Many of them, consequently, are not standard products of the manufacturers. Types and sizes are selected by laying out on the drawing board the rail and joint-plate sections and then prescribing a bond that has plenty of clearance.

The extreme care with which the New York Central & Hudson River Railroad Co. installs their pin-terminal bonds has already been referred to. The reported price of 35 cents per bond for labor on installation is an indication of the grade of labor and the care employed. It is said that bonds are installed in only freshly drilled or reamed holes, and that the bond terminals are cleaned and polished before they are expanded. A driving fit must be secured and if a hole is found to be larger than the bond terminal it is reamed out and a larger terminal inserted, or if the difference is small a larger expanding pin is used. Finally, the expanding mandrel and pin must be of the correct diameter to insure proper expansion. Too large a pin will tear the metal, while too small a pin will not insure complete expansion. Three companies are manufacturing the standard 16-inch 500 000 cir. mil stranded bond employed by this road, which is a special product, as no other operating companies use the same bond.

That the careful and expensive methods of bonding employed by this company are fully justified is indicated by the extremely small percentage of failures recorded on page 36 of this paper. The following set of specifications which are required by the Bay State Street Railway Co. are similar to those required by other large companies employing pin-terminal bonds and may prove of interest to bond purchasers:

RAIL BOND SPECIFICATIONS.

Definition of terms.—The word "company" where occurring in this specification shall mean the purchaser of the material hereinafter referred to, or its duly authorized representative.

The word "contractor" where occurring in this specification shall mean the party accepting the order to furnish the material hereinafter referred to, or its duly authorized representative.

General description.—The materials required under this specification are 4/0 A. W. gauge capacity bonds, for bonding around track joints.

The completed bonds and the materials of which they are made shall conform in design and dimensions to the company's standard drawings, hereby made a part of this specification and to the following requirements and tests:

Conductor.—All bonds shall consist of the required number of annealed copper wires or ribbons, free from splints, flaws, or other defects, and having an aggregate cross sectional area, when measured at right angles to the axes of the individual wires, at least equal to that of 4/0 American wire gauge.

Each of the individual wires or ribbons shall have a conductivity of not less than 98¼ per cent of standard annealed copper at 20° C.

Where stranded bonds are required the wires shall be concentrically stranded together in spiral layers having at least one complete turn in each 5 inches of conductor.

The copper wires shall not vary more than 1 per cent from the nominal diameter.

The copper ribbons shall not vary from the nominal widths and thickness more than the amount shown in the following table:

Thickness, in inches	Variation, in inches	Width, in inches	Variation, in inches
0. 010–0. 050	0. 001	0. 10–0. 250	0. 003

Terminals.—Where copper terminals are required they shall be in effect a unit with the conductor. This may be accomplished by upsetting the head from a portion of the conductor or by welding drop-forged terminals on the conductor, in which case the union between terminals and the cable shall be a clean weld, free from oxide.

The terminals shall be of uniform size and shape, free from cracks, burrs, fins, slivers, and hard spots, and any machining on terminals shall be followed by careful annealing.

The surface of the terminals as called for on the drawing shall be milled smooth or otherwise finished, the resulting surface to be strictly equivalent to that obtained by careful milling.

Where steel terminals are required they shall be made of steel of good quality, soft, and carefully shaped to the dimensions specified, and shall be thoroughly tinned inside and out before soldering to the conductor.

The soldered joints between the terminals and cable shall be carefully made with half-and-half solder and shall be free from imperfections of adhesion, excess of solder, or any other defects.

Tests—Union between conductor and terminals.—All bonds with copper terminals may be tested as follows to determine the character of the union between the head and conductor:

The stud of the bond shall be sawed lengthwise into four equal segments, allowing the saw to cut to but not into the conductor:

These segments shall then be bent back, tending to separate the welded parts. If a clean, bright fracture is exhibited, with a surface entirely free from dark oxide, the weld shall be considered satisfactory. It is not essential that the lines of the individual wires or ribbons be entirely obliterated.

Flexibility.—The test for flexibility hereinafter described is not made a condition of acceptance, but may be made at the option of the company and accorded due weight in the determination of the relative excellence of the bonds submitted. This test shall be made by holding rigidly one terminal of a bond while the other end is given a longitudinal movement of three-sixteenths of an inch, and a transverse movement of three-sixteenths of an inch, and continuing the movement until the first ribbon or wire breaks.

Inspection.—Samples shall be selected at random from each type and kind of bond received for inspection and determination if they comply with the specification; the samples shall consist of two bonds from each 100 and at least two bonds if there are less than 100 bonds.

Rejection.—If 10 per cent of the selected samples fails to comply with the requirements of the specification all bonds represented by these samples may be rejected and returned at the expense of the contractor.

Method of shipment.—All bonds shall be so packed for shipment that they will be suitably protected from injury, each package being plainly marked with the number, type, and length of bonds, and the number of the company's order upon which shipment was made.

The argument that it is easier to obtain uniform results with the pin-terminal than with the compressed-terminal bond is largely based on the assumption that it is easier to drive a pin into a bond terminal than to properly adjust and manipulate a compressor. This is no doubt true, but it is also a fact that workmen frequently drive the pins in crooked and thereby fail to get a uniform expansion.

In the installation of compressed-terminal bonds not only must the compressor be properly adjusted so as to get an even bearing on the bond terminal but the maximum compression must be obtained in order to secure the best results. It is also important to keep the point of the compressor in good condition, and the axis of the screw should be at right angles to the opposite face of the compressor. The difficulty of knowing when complete compression has been obtained has led some of the operating companies to the practice of testing each bond at the time of installation. If it does not come up to the proper standard the compressor is applied again or a new bond installed.

One of the manufacturing companies is attempting to provide for this insurance automatically by building a compressor which will shear out a button of sheet metal when the proper pressure has been reached. Workmen will then be required to turn in a button for each terminal compressed at the close of each day.

Granting that attention to these details is obtained only by conscientious and experienced workmen, it is also true that a greater variation in the size of holes is permissible with the compressed-terminal than with the pin-terminal bond. The great care exercised in getting holes of exactly the right size and the rigid specifications regarding the diameter of pin-terminal bond studs is necessary on account of the small amount of expansion that can be obtained in this type of bond. On the other hand, although not good practice, pressure can be applied with a screw or hydraulic compressor until a comparatively loose bond terminal has been made to fill the hole.

Summing up the arguments we are inclined to believe that honors are about even respecting the two types, and we are led to the following conclusions:

Excellent results are obtained with the compressed-terminal bonds when they are carefully installed by experienced men. Inexperienced, untrustworthy, or careless workmen should not be employed for their installation. The compressor should be kept in good condition in order that complete and even compression may be obtained. The testing of bonds immediately after installation is also a good practice. Failure to comply with these requirements is likely to result in poor contacts, followed by corrosion and rapid deterioration.

Results equally as good as those obtained under the best conditions with the compressed-terminal bond may be secured with the pin-terminal type when careful attention is given to the details of installation, particularly to obtaining a driving fit for the bond terminal before driving the pin. This condition can be controlled within narrow limits by specifying only machined-terminal bonds and giving close attention to the grinding of drills. The reaming of all holes with a straight reamer is a good practice and will add greatly to the uniformity of results. Moderate and fairly uniform results can be obtained with the pin-terminal bonds when installed by ordinary inexperienced laborers if they are provided with uniform bonds and pins as well as drills which have been ground at the shop. This is owing to the fact that under these conditions the personal element has been largely eliminated, and so long as

the pin is driven home there is a fair assurance that a good and permanent contact exists.

Compressed-terminal bonds are often excluded from use on rapid-transit lines where the compressor over the rail would offer a hazard to the safe passage of trains, also from special work where the sharp angles of the frogs sometimes prevent its use.

Pin-terminal bonds are excluded from use on elevated roads and other tracks where wooden or steel guard rails prevent the use of a hammer in driving the pins. The steel pins in pin-terminal bonds are subject to corrosion and should be used with caution where they are likely to be subjected to excessive moisture.

The following code of instructions for the installation of pin-terminal bonds is given by Howard H. George in the Electric Railway Journal of September 19, 1914. It represents the best modern practice and has been incorporated in Prof. Richey's Electric Railway Handbook. All of the 13 rules, with the exception of 10 and 11, apply equally well to compressed-terminal bonds.

CODE OF INSTRUCTIONS FOR INSTALLING RAIL BONDS

1. Every roadmaster and foreman should see that one or more men in each gang are taught the proper way of installing bonds, and should be sure that any bonding done thereafter is performed by these men.

2. When renewing rail or joint plates on single track in operation, care should be taken not to open or disconnect both rails at the same time, as this would open the return circuit by which the current returns from the cars to the power house. When it is absolutely necessary to open both rails, a long copper jumper should be installed to connect the open ends so that the path of the return circuit shall not be interrupted. This applies more particularly to road ends and interurban lines.

3. Whenever any track is opened up and any ground wires for electric lights, lightning arresters, or other electrical apparatus which should be connected to the rail are found disconnected, they should be reported at once to the bond inspector, or distribution department, so that they may be repaired before the track is closed up. This is very important and should receive careful attention.

4. No bond holes should be drilled until just before the bonds are ready to be put in. There are, of course, times when it is desirous to have the holes drilled before the rail is placed on the ties. When this occurs, it is necessary to place a tight-fitting plug in the hole as soon as it is drilled to avoid any possible introduction of moisture. To drill a hole a day or two before and not protect it from moisture means a film of rust in the hole, which will greatly increase the resistance of the joint.

5. Old bonds should never be used again, because they become battered up in driving them out. Then, when they are put in again they will not make good contact with the rail, which means a poor bond. Where a bond is removed from the rail it is not advisable to use the same hole in putting in a new bond, unless some pre-

cautionary methods are used. The proper way is to drill a new hole, but as this is not allowable in some types of rails, ream out the old hole and use a bond with a special large size terminal.

6. Great care should be taken with the drills used in making bond holes. If an improperly ground drill is used the hole will be irregular and oval shaped, thus giving a poor contact between the terminal and the rail. All dull and broken drills should be carefully boxed, labeled, and sent to the shop to be reground, where the company has installed a special machine for the purpose to do the work perfectly and at much less expense than could possibly be done by hand.

7. In drilling bond holes never use oil to lubricate the drills. It is better not to use anything, but where it is absolutely necessary to use a lubricant, nothing more than a soda solution should be employed.

8. Holes, after being drilled, should be carefully cleaned of any chips and wiped dry of any solution that may have been used to lubricate the drills. The holes must have a smooth and dry surface, so that the bond terminal will make a good contact all around.

9. With a proper size hole, the bond terminal will make a very snug fit, not small enough to have to be driven with a heavy maul nor large enough to be put in easily with the hands. It should require a couple of taps with a hammer weighing about 3 pounds. With a heavy hammer or spike maul the head of the bond terminal is very likely to be battered and the taper punch struck on the slant, causing it to split and bend the terminal.

10. After the bond terminals are in position, always drive the long steel taper punch entirely through the terminal, taking care to strike the punch squarely on the head. The small end of this punch should be dipped in some kind of heavy grease, such as track grease, just before it is driven through each terminal. The grease will lubricate the sides of the punch, thereby expanding the terminals and not drawing the copper with the punch.

11. Drive into each of the expanded terminals one of the short drift pins, thus expanding the copper a little more. This pin should be driven in until it is just flush with the head of the bond terminal.

12. The bond should then be shaped by straightening out the bond conductors, and forming them so that they will not be cut by either the track bolts or the splice bars. If it is a 36-inch bond, it should be so shaped that it will in no way interfere with the removal of the splice bars.

13. The bond, and particularly the bond terminals on both sides of the rail, are to be painted with some good weatherproof paint, care being taken to see that the paint fills the space back of the terminal heads.

(*b*) STRANDED V. RIBBON BONDS.—Referring to the tabulation under question 3, on page 29, we find that a total of 579 200 stranded concealed bonds were reported, as against 214 200 ribbon bonds. Considering that the section of the ribbon bonds is much better proportioned for the space usually provided for concealed bonds, this apparent preference for the stranded type may seem surprising. Manufacturers who have conducted laboratory life tests on the two types differ as to their relative abilities to with-

stand vibrations. The American Steel & Wire Co. states in their general catalogue that the stranded bond will remain intact longer than the ribbon bond, while the Electric Railway Improvement Co. affirms that many vibration tests on short head bonds have demonstrated that the ribbon bond will outlast the wire type. This seems to be another case where theories and laboratory experiments offer little evidence as to what will happen under the peculiar exigencies of service. The fact is that the majority, though not all, of the operating companies are using and prefer the stranded bond for concealed work and say that it is giving better satisfaction than the ribbon type and is not so sensitive to vibrations and the corrosive action of the joint plates.

The secret of the matter no doubt lies in the fact that the conductors of the ribbon bond, not being twisted or wound together, are easily separated and isolated. The space provided for concealed bonds is wedge shaped, as seen in Fig. 15, and the movement of the plates tend to work the ribbons and strands upward under the fishing surface of the rail head. This is a common complaint, and has been mentioned by a number of engineers. The wires of the stranded bond, being twisted together, are not so likely to become separated and broken by this action.

The effect of loose joints on head bonds installed in macadam or earth streets is similar to that on concealed ribbon bonds described above. Dirt works in between the ribbons, which are gradually separated and brought to the surface by the continual motion of the joint. This trouble has been recognized, and is now being largely overcome by the application of a clip around the body of the bond, which prevents the separation of the strands. This clip is illustrated in Fig. 17.

(*c*) Use of Solder and Alloys with Mechanically Applied Bonds.—The large number of bond failures in past years resulting from corrosion of mechanically applied terminals have led a number of companies to adopt the use of solder or a plastic mercury alloy as a third or intermediate metal between the copper and steel. In some cases compressed-terminal and twin-terminal bonds have been installed with solder, in other cases the terminals have been tinned either at the factory or on the ground before installation, while in still other installations both the steel of the

rail and the bond terminal have been amalgamated. While these various practices have found rather wide application and have many adherents, the manufacturers of bonds are a unit in their belief that the copper to steel contact can not be improved upon. They argue that the introduction of a third metal, having a specifically high resistance, between the copper and steel will not only add to the contact resistance but might also be the source of a chemical action which will hasten rather than delay corrosion. To the argument that a third and soft metal is needed to take up the difference in expansion between copper and steel, they reply that the process of expanding or compressing a copper terminal so hardens it as to give it sufficient elasticity to take up this slight difference in expansion itself. In the absence of experimental data to substantiate these theories we are again forced to base our conclusions upon the best modern practice resulting from years of experience and upon the opinions of prominent engineers. We will consider the practices of soldering, tinning, and amalgamating in the order in which they are named.

The several methods of soldering compressed-terminal bonds which have been used are well described in the following extract from a letter received from the Ohio Brass Co., which developed the thermobonding process, in answer to an inquiry requesting information on the subject:

The compressed-terminal type of rail bonds has had the most general use in the past, due principally to the fact that it can be installed in a satisfactory manner with the comparatively low grade of labor that must be relied upon for work of this kind. One of the chief objections to the compressed-terminal type of rail bond has been the rather small contact area between the terminal of the bond and the rail. In case the bond is not properly compressed, the contact surface would corrode, further reducing the efficiency of the bond. In order to overcome this difficulty many railroads make a practice of soldering the head of the bond to the rail after it has been compressed. With this method it is customary to tin the bond terminals before they are compressed and after the compression to heat them with an ordinary blow torch, applying solder, so as to form a perfect contact between the head of the bonds and the rail, thus supplementing the contact secured by the compression and excluding the moisture from the plug portion of the bonds, at the same time giving an electrical contact which is not liable to deteriorate. The soldering process, however, adds considerable to the expense of the installation.

The O–B thermobonding process was developed with a view of securing the advantageous results of soldering compressed-terminal bonds, at the same time furnishing a simple and cheap method of making this application. The charge of thermite is set off on the opposite side of the rail from the bond head and generates sufficient heat so

that the bond head can be soldered to the web of the rail. Many of the largest roads in the country using compressed-terminal bonds with solder changed over to the thermo process as soon as it was put on the market, and a great many bonds have been installed in that manner. However, it is an added refinement which is not considered essential, and as it adds considerable to the expense of the installation it has not had a universal use. The process requires some care in the installation, and for this reason, where a low grade of labor is used, further difficulties are encountered.

Where a railway wishes to secure a very high grade of bonding and is willing to take the pains to use the proper care in installing the bonds by the thermo process, it is a very excellent method and is quite successful.

The thermobonding process here described has fallen into disrepute, and disuse so that at the present time it is employed very little, if at all. This has been the result, not only of the causes mentioned in the above quotation, but because of the injury done to the bond terminal and the web of the rail by the excessive heat generated by the thermite. We quote Company 16, on whose tracks a few bonds were soldered for demonstration purposes:

After three years the bonds were removed for inspection, but we are sorry to say that they were in bad condition. The terminals were black and not soldered to the rail at all in the hole, and the excessive heat from the thermite had burnt the rail, which made it brittle and caused the steel to rust and depreciate.

Conditions similar to these were also reported by A. P. Way, electrical engineer for the American Railways Co. Company 15 says regarding the thermobonding process:

About four years ago a thermosoldering process developed by the Ohio Brass Co. was made a part of the standard process of installing a bond. It is supposed to make a complete union between the copper bond and the rail. In most cases it appears to do so, but there have been cases where such bonds were removed several months after installation and the contact between bond and rail has been black instead of bright, thus showing poor contact. This may have been due to poor workmanship in the installation, particularly since bonds installed by this process test good after installation.

A test made by the Chattanooga Railway & Light Co. in November, 1910, shows the resistance of the thermo process bond contact to be approximately one-half the resistance of the compressed type without soldering.

In addition to Companies 14 and 15, which have employed the thermobonding process, may be mentioned Companies 7, 20, and 26, which solder their stud and twin terminal bonds by the aid of a blow torch.

The following letter from Company 20, describing the method as practiced in Tacoma, Wash., will be found of interest:

We are sending you, parcel post, one of our standard 250 M c. m. twin-terminal bonds. The American Steel & Wire Co. have made a special die for the bonds they

furnish us. You will notice that the face of the terminal which comes in contact with the ball of the rail is a flat smooth surface. In applying these we are very careful to see that the ball of the rail is chipped smooth and deep enough so that all rust spots are cut out. Although the terminals are tinned, we redip them immediately before they are applied. We also are careful to see that the holes in the ball of the rail and the chipped surface is perfectly clean and well tinned. The bond is driven with the rail hot and the solder fluid. After the bond is in place, solder is applied to the upper edge of the bond with an iron which makes a reinforcing fillet.

Before adopting this type of bond as a standard, we applied a number of them without solder. Resistance measurements were taken immediately after the bond was applied and at intervals thereafter. We noticed in a number of cases that the resistance of the bonds increased, in some cases slightly and in some cases materially. Since we have been using solder in the application of this bond, we have made a large number of resistance measurements and have not noticed any change in the resistance of the bond.

The bond here described is similar to the Form C twin-terminal bond, but having a broader face and a square shoulder to hold the fillet of solder.

There seems to be a fairly general agreement that solder improves the contact of mechanically applied bonds, but that when applied by the thermo process the chance of burning both the bond terminal and the rail are so great as to offset the benefits that might accrue therefrom. In view of the excellent results which are being obtained with the compressed-terminal bond under the present improved methods of manufacture and installation, the additional expense of soldering this type appears to be hardly justifiable. The soldering process requires skilled labor, additional time, and extra material. If half this time and expense be devoted to careful and improved methods of drilling holes and compressing the bond terminals, equally good results could be obtained. The use of solder in connection with twin-terminal bonds will be further discussed when considering that type.

The process of tinning stud-terminal bonds before installing them has been employed by a number of companies, and apparently with general success. One of the strongest advocates of this practice is found in E. Heyden, superintendent of overhead construction for the Indianapolis Traction & Terminal Co., who is very positive in his belief regarding its value. Mr. Heyden states that he has used tinned-terminal bonds for years, and that in removing bonds from old rails he has invariably observed that corrosion has been much worse on bonds which had not been

dipped. He goes further and says that with a bond tester he is able to distinguish between dipped and undipped bonds when testing the resistance of rail joints.

Tinned bonds are also being used by the Empire United Railways, of Syracuse, where it is stated they show less corrosion than undipped bonds.

The process of amalgamating bond terminals before compressing them is now finding favor with a number of operating companies, among which is Company 25, from whose report the following quotation is taken:

> After using many types of bonds and rail joints, the writer has standardized on the use of compression bonds in connection with which is used the so-called H. P. Brown pastic and solid alloys. These alloys have proved very valuable, in that they take care of any grooves which may be cut in the bond hole when drilling the rail for a bond, and also, being live materials, take care of the difference in coefficients of expansion as between copper and steel at the connection of the bond to the rail. These alloys also form a protective coating over the copper and steel, preventing corrosion near the point of contact.

These alloys have also been used by the American Railways Co., which believes them to be valuable in excluding moisture from the bond terminal.

These alloys are useful only where they are confined, as they soon corrode and lose their effectiveness when exposed to the atmosphere. In the New York power stations, where they were used on copper switches to reduce the contact resistance, they were effective for about three months, after which time the switches showed a higher resistance than before the application of the alloys.

Although the practice of tinning and amalgamating stud-terminal bonds has not been very extensively employed and comparatively little information regarding it is available, it appears that in some installations they have proved very valuable. Both processes are quite inexpensive, and on installations where corrosion of terminals has been a chronic trouble they can, no doubt, be used to advantage. The utility of many materials and practices of this nature depends largely upon the personal element of the workmen involved. One man may learn how to apply compressed terminal bonds and obtain good and uniform results by his individual methods. The same man may utterly fail to get results

with pin-terminal bonds or with soldered or amalgamated compressed-terminal bonds. Splendid results obtained with the use of any type of bond or material are usually the result of the individual efforts of some person who has mastered that particular problem.

(*d*) MECHANICALLY APPLIED HEAD BONDS.—The twin-terminal bond and tubular-terminal, or O–B, type J bond, shown in Figs. 7 and 8, are included under this heading and are so similar in construction and with reference to their features of installation that they may well be considered together.

These types were developed as the result of a demand for a bond that could be installed without removing the joint plates and without undue interruption to traffic. Experience had demonstrated that long bonds which spanned the joint plates were subject to theft, and the types here mentioned were made as short as possible in order to reduce this loss as well as for the sake of economy. The short length has naturally resulted in considerable breakage from vibration, particularly on loose joints, and this is perhaps the most prevalent cause of failure.

While these types are best adapted to open track where they are not subjected to vehicle traffic they have been used to some extent in earth and macadam streets. The cost of renewing a concealed bond in city streets is shown by figures in Section III to range from $1 to $3, depending upon the nature of the pavement. It is argued that the cost of installing a short head bond is so small in comparison to this that a company is justified in its use, although the depreciation in city streets may be high.

Very little testimony has been secured regarding the use of the tubular-terminal bond, as this type has been on the market but a short time. The extent to which it is being adopted on new roads, however, is not only evidence of the general demand for a short head bond but an indication of faith in this particular type. The following information is pertinent regarding its use.

In answer to an inquiry on the subject the Northern Ohio Traction & Light Co. says:

> Replying to your letter of the 2d instant, I wish to advise you that the O–B type J rail bond which we have used has given us very satisfactory service.

The Detroit Railway has the following comment to make:

> Replying to yours of the 2d instant, relative to our experience with the O–B type J rail bonds, I beg to state that we have used a great many of these bonds on suburban work and they seem to be working out very well. I do not recommend them for city street work or for places where vehicles can in any way strike them, as they, like all other bonds of this character, are liable to shear off from the rail.

George F. Silvia, electrical superintendent for the Albany Southern Railroad, states that a systematic rebonding of all the tracks on that road will soon be commenced and that the O–B type J bond will be used exclusively. He believes that where these bonds fail others should be installed by drilling new holes in the head of the rails, as it would not be practicable to attempt to drill out the old terminals.

Recent technical press notices state that on the new Grand Rapids-Kalamazoo line, 50 miles in length, and in the construction of the Fort Wayne & Northwestern Railway the O–B type J bonds are being used.

The testimony relative to twin-terminal bonds is more abundant. Company 11 employs 60 000 and Company 42, 33 000 of the total 113 700 bonds of this type reported. On both roads its use is confined to open track. As these companies are among the largest users of twin-terminal bonds in the country their experience should be significant. Company 11 says in answer to question 6:

> Twin terminal and compressed terminal bonds usually last as long as the track; the percentage of failure is very small.

Company 42 reports that in the seven years of operation 7357 bonds on an original installation of 33 000 have been replaced. Of these 800 had been stolen. This is equivalent to an annual failure of approximately 3 per cent.

Good results have also been secured by the Cincinnati Traction Co., where a suburban line of 25 miles in length has been bonded with twin-terminal bonds. Practically no failures have been experienced and the bond is said to be easily installed by ordinary unskilled labor. In the May, 1915, issue of Electric Traction is a description of the new Waterloo-Cedar Rapids line in Iowa; 4/0 twin-terminal bonds are employed and were installed at the rate of 100 bonds per day by four men with electric drills.

In contrast to the complimentary experience of these companies is to be found the opinions of a number of engineers who for one reason or another have not been pleased with this bond. The Bay State Street Railway Co. reports that they have used some twin-terminal bonds but found them short lived on account of breaking at the terminals or loosening of the studs.

Company 24 reports that of a trial installation in 1910 of 1000 twin-terminal bonds 75 per cent were stolen in 1913–14. With a number of these the studs, as well as the body of the bond, were removed showing that the contact was poor.

The Virginia Railway & Power Co. installed a few of these bonds but was not entirely pleased with the results obtained.

Several engineers have been consulted who object to drilling into the heads of rails, saying that it is likely to weaken them and increase the chance for cupping. This argument, however, does not appear to be founded on definite facts.

That the contact resistance of twin-terminal bonds, as ordinarily installed, increases gradually with time seems to be a well-established fact. Some of the answers to question 18 giving information on this point are here repeated. Company 7 says:

A new twin terminal bond will equal about 3 feet of rail, when the old ones will average about 4½ or 5 feet.

Company 11.—We have found no difference in resistance between old and new bonding, so long as the bonds remain unbroken and their terminal contacts are unimpaired.

This statement is made with reference to twin-terminal and compressed-terminal bonds.

Company 26.—Tests of compressed-terminal bonds and twin-terminal bonds are practically the same, 4 to 4½ new, 5 to 6 when old.

The letter from Company 20, quoted above, also states that the resistance of unsoldered twin-terminal bonds increases after installation, in some cases slightly and in some cases materially.

The Bureau of Standards recently tested 40 joints on the Washington, Baltimore & Annapolis Railroad near Washington. These joints were bonded with 4/0 twin-terminal bonds which had been in service about seven years on 80-pound rails. The test was made on 3 feet of joint, and the highest and lowest resist-

ances were 9.9 feet and 6.0 feet of adjacent rail, respectively, the average being 6.90 feet, or 0.0000828 ohm.

A test made by the Bureau of Standards on a single-rail joint, newly bonded by the American Steel & Wire Co., with one 4/0 twin-terminal bond, showed a 3-foot joint with plates bolted in place to have a resistance of 0.0000349 ohm or 2.91 feet of 80-pound rail and with plates removed to have a resistance of 0.0000745 ohm, which is equivalent to 6.2 feet of the adjacent 80-pound rail. While this latter figure is not materially less than the resistance of the average old joint it is much lower than that of individual joints. The joint plates undoubtedly add somewhat to the conductance of joints even on old installations but just how much it is difficult to say. The tests conducted by the Bureau of Standards on unbonded joints which have been referred to before indicate that on old joints the function of the plates as far as aiding the return circuit is concerned is practically nil. It is altogether possible that observed changes in the resistance of bonded joints have frequently been attributed to deterioration in contacts when as a matter of fact they have been largely the result of loosening and rusting of the joint plates.

Considering all of the information at hand it appears to be more than probable that twin-terminal bonds as well as other mechanically applied bonds gradually increase in resistance with time. This increase in resistance with the twin-terminal type, though small in some cases, becomes quite appreciable in others, and on the average remains within the limit of good practice for a period of years, on joints which have been carefully installed.

That the use of solder in connection with these bonds will forestall this contact depreciation is undoubtedly true. Its adoption, however, should depend upon local conditions and the personnel of the force of workmen.

Summing up the features of the mechanically applied head bond we find the following to be applicable to both types here discussed.

These bonds are short and therefore comparatively inexpensive. They can be rapidly installed with very little interruption to traffic, the total cost of installation, including bond, being about 50 cents each on new work. When used on city streets they can

be installed without removing joint plates, but on this type of construction they are subjected to vehicle traffic, which is likely to shear them off of the rail. On open track they are subject to theft, but this loss is much smaller than with longer bonds. It can be reduced by painting with black paint, thus rendering the bonds less conspicuous. In some cases they have been protected by iron plates bolted to the joint. Owing to the shortness of the bond, failures frequently occur from breaking of the strands, particularly on poorly maintained joints. The contact between copper and steel slowly, though as a rule not seriously, depreciates. This may be prevented by soldering and to some extent by tinning the terminals.

(*e*) Electric-Weld Bonds.—The practically universal demand for something better than a soldered contact and a substitute for the purely mechanical contact has been responsible for the wide adoption of the electric-weld bond within the past few years. The 720 000 of these bonds reported by the operating companies is an indication of the extensive use which it has found during the comparatively short period of its manufacture. Although it has been used for the most part as a head bond it is now coming into use more and more for concealed application to the web of the rail.

There seems to be practically no question regarding the permanency of the contact that these bonds make with the rail, but some criticism has been directed against some of their other features, particularly to the breaking of the ribbons and to the inconvenience of using the bonding car on tracks over which traffic must be maintained. The question has also been raised as to what effect if any the welding heat has on the steel of the rail. The following quotations from written reports and conversations, it is hoped, will throw some light on these questions.

The New York State Railways, of Syracuse, are using large numbers of electric-weld bonds where they are believed to be the best bond available. The engineers state that they can be installed in paved streets by removing a couple of bricks and the expense is not over 60 cents per bond, while the replacement of a concealed bond on similar construction would cost about $3. When installed in macadam streets a wire is twisted about the middle of the bond to prevent the ribbons from separating and

working to the surface. The need of this precaution has been recognized by the manufacturers, who now provide bonds with a clip as shown in Fig. 17. The company has been using the EA type and has experienced a rather high percentage of failures from breaking of the ribbons. Recently, however, the ET type has been adopted from which much better results are expected. These two types are shown in Figs. 4 and 5 and have been previously discussed.

The New York Railways, of Rochester, are using practically nothing but electric-weld bonds. On new work where there is heavy traffic a concealed bond is welded to the web of the rail and an EA and an EB type to the head, making three bonds per joint. Very little trouble from traffic is experienced in paved streets, but in macadam and earth streets a number of bonds have been broken by vehicles. This company has also recently substituted the ET for the EA type.

The Hudson & Manhattan Railroad Co. is using 600 000 cir. mils electric-weld bonds and finds them satisfactory for new work. They are not so satisfactory for maintenance as the bonding car can not be derailed in the tunnels, and the expense of operating it at night for small repair jobs is excessive. This company claims that if the carbon electrodes are kept well back on the bond terminal and not allowed to fuse the ribbons near the bend in the bond that good results may be obtained with the EA type.

COMPANY 14.—After a great deal of experience here and elsewhere with various types of bonds, we have come to the conclusion that an electric-weld bond of considerable length to give the bond the proper flexibility is the only type of bond to use.

The experience of Company 13, which has been quoted under answers to question 6, is similar to that of other companies in that the ET bond has been substituted for the EA type and better results are expected from it.

Unfortunately, this new type has not been in service a great while and the companies are not prepared to make definite statements regarding it. The fact, however, that no complaints have been heard concerning it is good evidence that it is an improvement upon the EA type and will show a much smaller percentage of failures.

Regarding injury to the rail by heat there seems to be very little definite information. A number of engineers have expressed a question or fear regarding this point, but with possibly one or two exceptions no company has definitely reported any broken rails from this cause. The Cleveland Railway Co. states that several rails have cracked where bonds have been copper welded to the web of the rail.

The Los Angeles Railway, which has over 300 000 electric-weld bonds, writes the following letter in reply to an inquiry on this question:

> In reply to your letter of the 3d instant regarding broken rails as a result of heating the web in applying bonds, wish to advise that in the several thousand brazed bonds we have installed under the plates or concealed on the web we have never had a broken rail caused by heating the web.

It is reported that some fractures have occurred in rails through holes which had been punched in the web, but that such failures are easily prevented by reaming out the holes, thus relieving the strain around them.

In the absence of more definite complaint on this score it is safe to say that the injury to rails resulting from the heat generated in welding rail bonds is so small as to be negligible and can be practically disregarded in the selection of a type of bond.

The matter of interruption to traffic is something that will depend upon local conditions and will have to be met by each company in a manner depending upon a variety of circumstances. A number of companies operate their bonding car at night on tracks from which it is difficult to divert the day traffic. Upon suburban tracks, for maintenance work, it is usually possible to sidetrack the bonding car, or if not it may be derailed to accommodate infrequent traffic.

The following is a summary of the properties and features of the electric-weld bond:

The bond is made for either head or concealed application. Either type can be installed on new work for from 50 cents to 60 cents. The head bond is short and has experienced a rather high percentage of failures from the breaking of the ribbons, as well as from ignorance and carelessness in its application. Modern improvements are materially reducing these failures.

The bond makes a very low-resistance contact with the rail, which does not depreciate with time.

The shortness of the bond and the strength of the contact has made the theft of this type, on interurban lines, far less than that of other types.

The bond is used successfully in paved and other types of city streets, where it can be cheaply installed. Being subjected to vehicle traffic, however, occasional failures must be expected. Where used in earth or macadam streets a clip should be employed to prevent the ribbons from working to the street surface.

The installation of this bond is accomplished with the aid of a bonding car, the first cost of which is not justified on small properties.

Maintenance bonding can not be accomplished without interruption of traffic or considerable inconvenience in derailing the car or operating it at night.

Some fear has been expressed regarding the heating of the rail webs, but the failures from this cause have been so infrequent that no great importance should be attached to them.

The following account of the apparatus and methods used in connection with the electric-weld and the copper-weld rail bonds was furnished by the Electric Railway Improvement Co. Some of the apparatus referred to is shown in Figs. 6 and 6*a*.

ELECTRIC-WELD RAIL BONDS

On direct-current lines electric-weld rail bonds are installed with a small car measuring 6 feet 10 inches in length and about 5 feet 10 inches in width. The frame of the car is of structural steel covered with an oak floor and carried on four 20-inch wheels.

The electrical apparatus consists of a rotary converter and transformer with the necessary switches, circuit breakers, controller, resistances, etc., for its safe and convenient operation.

The rotary converter is provided with a clutch and is used as a motor for the propulsion of the car along the track.

The bonding clamps for electric welding are located at both sides at one end of the car over the rails and have adjusting screws with hand wheels for bringing the same into position for service.

To avoid interference with traffic, a screw jack with bevel-gears termination in cranks at each side of the car, is fixed under the center of the car frame. By means of this jack the car can be raised for the purpose of turning and rolling from the track to avoid interference with traffic. Depending on conditions, the car can be removed from the track in from one to one and a half minutes and may be replaced on the track in a similar length of time.

The entire car is covered with a canopy top which carries the trolley pole.

On alternating-current lines the car is not necessary, and the AC voltage is carried directly from the trolley to a portable transformer. The welding clamp is attached to the transformer, which is provided with wheels for rolling along the track. This apparatus may be lifted from the track in a few seconds.

On high-tension lines the trolley voltage would pass through a step-down transformer before entering the portable.

For electric welding, a current of from 25 to 50 amperes is drawn from the trolley; this varies, depending on the trolley voltage and the size of bond to be attached. For welding a 4/0 rail bond to the rail, an alternating current of about 2500 amperes at 5 volts is employed, which is obtained on a direct-current line by converting and transforming about 25 amperes at 550 volts taken from the trolley. To make a weld, the current is applied for a period of from 45 seconds to 2 minutes, depending on conditions.

An average of 100 4/0 bonds per 10 hours may be installed with the car operated by a bonder and two helpers. For best results the bonder should be a man of average intelligence, while the two helpers may be laborers.

The welding apparatus is not sold by the manufacturer, but is put out under a lease. The clauses of most importance in the lease are those stipulating that during the life of the patents all rail bonds installed with the apparatus shall be purchased from the manufacturer at prices given in schedules attached to the lease, that the prices for bonds as given in the schedules are guaranteed by the manufacturer and the only change in the prices is due to the fluctuation of the market price of lake ingot copper in the bonds, that the manufacturer will furnish an expert to instruct the railway company's men in the proper operation of the apparatus, and at the expiration of the patents, under which the apparatus is leased, the manufacturer will transfer title in the apparatus to the lessee.

COPPER-WELD RAIL BONDS

The bonding cars as put out by the manufacturer carry a melting furnace suspended from the rear of the car for copper welding. This type of welding is especially adapted to the installation of large conductors around special work, and for attaching feeder cables, etc., to the rails. Bonds and cables of any capacity may be attached by this method. It is also used for joining third rails both electrically and mechanically together.

Copper welding is effected by pouring molten copper. A mold of suitable refractory material is employed, the size of the same depending on the section of the conductor and the size of the terminal or contact area desired. The end of the conductor lies in the terminal mold. A short channel connects the terminal mold proper with another chamber or reservoir. The rail having been properly cleaned at the point of weld, the mold with the bond wires is clamped in position. The molten copper, on being poured into the mold, impinges on the ends of the bond wires and the steel at the point of weld, and flows on into the reservoir, which finally becomes filled; continuing to pour the molten copper, it backs up into and fills the terminal mold. The excess of copper poured over that required to form the bond terminal proper has the effect of raising the temperature of the steel within the area of the bond terminal, to a proper welding heat; the steel then readily unites with the molten copper present.

The mold is then removed and the block of copper formed by the reservoir is taken off by cutting with a chisel the small section of copper which connects it with the bond terminal.

Copper welding may be used to electrically and mechanically join third rails.

The copper-welding outfit is also furnished independent of the bonding car. This particular apparatus is operated with kerosene oil, the crucible containing the copper being placed in a furnace similar to the one used in the coke outfits.

The copper-weld furnace car is equipped with from three to five kerosene furnaces and is designed for use on large installations.

The copper-welding apparatus is put out under a lease similar to that used in the case of the electric-weld cars.

This method of bonding, while being adapted for installing large cables, etc., is especially suited for bonding steam-road electrifications and new electric lines where the electric power is not available at the time of installation. For this type of work it is not necessary to have any of the apparatus on the tracks while operating. In fact, the single kerosene-furnace outfit may be carried along by two men, and need never occupy the track.

A modification of the Electric Railway Improvement Co.'s bonding car has been devised by the Cleveland Railway Co., and employed by them with considerable success, particularly for their special work bonding. In this process, which is described in the Electric Railway Journal of August 7, 1915, silver solder is used for a brazing metal instead of brass, and the union of the bond with the steel is therefore affected at a much lower temperature than is necessary with the standard equipment. It is claimed that the lower temperature and a different arrangement of electrodes enable the bond to be applied with a much smaller current than is used by the regular bonding car. This smaller current is obtained by a small rotary converter which can be mounted on a motor truck and connected to a step-down transformer by flexible conductors. The transformer is carried about from joint to joint over an entire intersection and with no interruption to traffic. It is claimed in Cleveland that this modified equipment and method has made possible the bonding of special work on a daylight schedule and with no broken rails or interruption of traffic.

(*f*) Oxy-Acetylene-Welded Bonds.—This type of bonding is accomplished by welding bonds with forged or cast terminals to the rail, usually the head, and employing pure or fluxed copper to build up the terminal of the bond along the rail head. So far, it has not found a very wide application, although it has been used in Minneapolis and St. Paul for a number of years with

FIG. 18.—*Apparatus for applying bonds with the oxy-acetylene flame*

FIG. 19.—*Apparatus for applying joint plates with the electric arc*

marked success. It possesses practically all of the advantages of the electric-weld bond and is free from the objection of requiring an expensive equipment and of interfering with traffic. Although it does not make quite as strong a contact with the rail as does the electric-weld bond, the contact is permanent and does not deteriorate with time. No injuries to rails have been reported from the use of the flame which apparently does not produce a higher temperature in the rail than is generated by the electric weld.

The Minneapolis Street Railway Co. has the following to say with respect to their practice of bonding:

The only type of bonds used during the past three or four years is a 250 000 cir. mils, U shaped, T head, bond welded on the side of the head of the rail, and in special cases on the side of the flange of the rail or on the base of the rail, using acetylene torch for welding. We use this type of bond on all types of construction from the light rail in earth streets to 100-pound guard rail on special work in paved streets, and on heavy T rail construction laid on concrete base with block, asphalt, or stone paving. We have at present between 14000 and 15000 such welded bonds in service.

Unskilled labor is used for bonding work; that is, the laborers are instructed in the proper handling of the tools and are then competent to do the work. It is found unnecessary to do any cleaning of the steel before welding bonds. For acetylene welding we use compressed acetylene in acetone tanks and compressed oxygen in tanks, with torch specially developed for this class of work. Pure copper is used for welding and no flux is required.

Complete cost of installing welded bonds of 250 000 cir. mils capacity in large numbers is between 50 and 60 cents per bond including cost of tools and machinery.

The failure of this method of bonding to have found more extensive use is apparently not the result of any defects or disadvantages connected with the process, but is more than likely the result of other causes. The recent concerted action of the manufacturers of both bonds and acetylene in providing and advertising proper bonds and material for this method of bonding will no doubt act as a great stimulus to its further adoption.

The following statements regarding this method of bonding rail joints have been abstracted from information submitted by the Ohio Brass Co. The apparatus referred to is shown in Fig. 18.

OXY-ACETYLENE-WELDED BONDS

For applying rail bonds the equipment consists of the necessary tanks of compressed oxygen and dissolved acetylene, which may be purchased by the railway companies direct from the manufacturers, who have warehouses and factories quite generally distributed over the country, thus insuring prompt and convenient service.

A pressure regulator and set of gauges are provided for both the oxygen and acetylene tanks. These are changed from tank to tank as they become empty, the empty tanks being returned to the manufacturers of the gas. A hose extends from each set of pressure regulators and is connected to a blowpipe or torch by means of which the gases are mixed and adjusted to give the proper condition of the flame.

A grinder for cleaning the rails will also be required and may be either of the electrical or hand operated type. A pair of colored goggles to protect the eyes of the operator will be found advisable for constant work, although the rays of light from the oxy-acetylene flame do not affect the eyes and skin as do the rays from the electric arc.

A small truck provided with handles will be found convenient for conveying the tanks of gas in service and can be purchased from the manufacturers or built from blue prints furnished by them.

Clamps for holding the bond to the rail while welding on one terminal will be supplied by the manufacturers, as will also the necessary flux wire. The latter is a metal especially prepared for the purpose of attaching the bond to the rail and for building up the head of the bond. It is three-sixteenths of an inch in diameter and is furnished in coils of about 50 pounds, which the customer should cut into suitable lengths.

For the proper application of bonds the work of only three or four men is required; a working foreman who watches and assists the blowpipe operator; blowpipe operator; and one or two grinders, the number depending on whether an electric or hand grinder is used. The grinders have time for other necessary duties as well.

The bonds require on an average about 3 cubic feet, at atmospheric pressure, each of oxygen and acetylene, and the actual time required to apply a bond is from four to five minutes.

(*g*) Bonding of Manganese and Other Special Work.—The recent use of manganese steel for special work which is too hard to drill has led to some difficulties in bonding. On this point Company 3, in speaking of electric-weld bonds, says:

This method of bonding manganese special work and steam-railroad crossings has been the only one that we have had any success with so far, on account of not being able to drill the manganese steel for compressed type. Some of the steel companies have undertaken to insert a soft-steel plug in the rail which can be reamed out to receive the bond terminal, but we find that the contact between the plug and steel is insufficient to carry current for any time.

Other companies report no such trouble from inserts in manganese steel, and the failures in this particular instance may have been due to the fact that the plugs were inserted in the rails by the aid of an oxyacetylene flame rather than having been cast in as is customary.

Company 27.—We bond around all important special work where any quantity of current is to be provided for by welding (with an oxyacetylene flame) heavy copper lugs to the web or base of the rail joint. To these lugs are attached stranded weatherproof covered cables of from 500 000 to 2 000 000 cir. mils, cross section, which spans the entire special work.

Question E–W–84 in the May issue of the A. E. R. A. asks what is the best method of bonding manganese special work and railroad crossings other than by using the plug holes provided. The following answers to this question as found in the June and July numbers are given below:

CHAS. E. FRITTS, ELECTRICAL ENGINEER, METROPOLITAN STREET RAILWAY CO., KANSAS CITY, MO.—We use copper cables underneath the special work and single bonds by brazing.

EDW. J. BLAIR, ELECTRICAL ENGINEER, METROPOLITAN WEST SIDE ELEVATED RAILWAY CO., CHICAGO, ILL.—The best way of bonding manganese special work and railroad crossings is to jump around them with copper-cable conductors, making the connection to ordinary rails behind the manganese special work.

A. V. BROWN, ENGINEER MAINTENANCE OF WAY, LAKE SHORE ELECTRIC RAILWAY CO., SANDUSKY, OHIO.—Run cable around manganese special work.

H. P. BELL, ELECTRICAL ENGINEER, SAN FRANCISCO-OAKLAND TERMINAL RAILWAYS CO., OAKLAND, CAL.—In bonding special work and railroad crossings, we have found, after much investigating, testing, and experience, that it is cheaper and more efficient to bond around crossings and special work (unless electrically continuous and easily drilled) with such size cables as the current density and voltage drop allowed demand at that particular location. We place such cable or cables in trunking filled with tar compound and bury them about 6 inches below the tie, connecting them to the through rails by means of seven-eighths-inch separate compression-bond terminals. Thus the track special work may be repaired or replaced without necessary repairs to bonding.

C. L. CADLE, ELECTRICAL ENGINEER, NEW YORK STATE RAILWAYS, SYRACUSE, N. Y.—The New York State railways' practice has been for the last seven years to install welded bonds on all track joints needing electrical connections. From our experience the welded bond adheres to manganese rail and special work as well as open-hearth and Bessemer steel. At railroad crossings in addition to bonding the joints each crossing is jumpered by placing a piece of 4/0 copper cable, or larger, around the crossing, so that in case the bonds on the joints of the special work are broken off the current will be carried through the jumper cable.

C. D. EMMONS, GENERAL MANAGER, CHICAGO, SOUTH BEND & NORTHERN INDIANA RAILWAY CO., SOUTH BEND, IND.—We use brazed bonds for all of our work.

H. G. THROOP, SUPERINTENDENT LINE AND BUILDINGS, NEW YORK STATE RAILWAYS, SYRACUSE, N. Y.—I believe that the best method of bonding manganese special work is to use welded bonds to the head of the rail, double bonding, using a 10-inch and 18-inch bond. The special work should also be cabled, i. e., one 500 000 c. m. cable installed for each track, attaching the ends of this cable to two 4/0 cross bonds welded to the rail at a point back of the special work each way from the crossing.

H. F. MERKER, ENGINEER MAINTENANCE OF WAY, EAST ST. LOUIS & SUBURBAN RAILWAY CO., EAST ST. LOUIS, ILL.—On account of the fact that special work with heavy cables carrying current around it may be considered dead for all the time except when a car is passing over it, there have been various methods of bonding used. In fact, some engineers have gone so far as to leave all bonds off of such special work. We know of no better way to bond special work than to leave a soft plug for drilling a

bond hole, but this hole may be placed at any convenient part of the special work piece and need not be in line with the bolt holes or near them, as all that is really necessary is one tap connecting it with the return circuit to keep the switch piece alive, and it is not necessary that each joint be bonded.

E. H. Schofield, Engineer Power and Equipment, Minneapolis Street Railway Co., Minneapolis, Minn.—In addition to cables spanning special work and bonded to rails, bonds may be welded by acetylene torch to the side of the head or guard of special work parts.

H. A. Clarke, General Manager, Ithaca Traction Corporation, Ithaca, N. Y.—My experience has been that it is the best practice to bond around such special work, using bond terminals of whatever type may be in use, soldered to sufficient length of oooo copper wire.

J. B. Tinnon, Engineer Maintenance of Way, Chicago & Joliet Electric Railway Co., Joliet, Ill.—I know of no better method of bonding manganese steel special work than by using the plugs in the castings. It is almost impossible to weld any kind of bond to the manganese casting and the heating of the casting would no doubt tend to destroy the value of the manganese steel. It is also nearly impossible to drill the casting, so I think that the method of using the plug holes and bonding to a through cable is the best method that has yet been developed.

H. E. Gough, Engineer, Elmira Water, Light & Railroad Co., Elmira, N.Y.—We double bond all connections in special work, drilling the bond holes on the ground. Better connections are insured if drilling is done on the ground rather than in the shop. It is also generally wise to provide supplementary bonding around special work where the traffic is heavy.

Geo. H. Pegram, Chief Engineer, Interborough Rapid Transit Co., New York, N. Y.—We find it most convenient and satisfactory to have all bonded holes provided by the manufacturers with copper plugs for signal bonding. We do not use manganese rail for negative return, as we have an opportunity to make use of the open-hearth steel guard rail for that purpose. The guard rail is bonded to manganese rail by means of clipped bonds.

In a paper presented at the annual convention of the Southwestern Electric and Gas Association, Galveston, Tex., May, 1915, G. W. Smith, engineer, San Antonio Traction Co., San Antonio, Tex., said:

Our experience with rail bonds as ordinarily applied has not been such that we felt justified in depending on them to carry the current around the special work. We tried to get information as to whether or not copper cables could be welded to the steel rail by the thermite process, but in so far as we were able to find out this had never been done, so we proceeded to do some experimenting. The result was that we succeeded in making a weld which gives a contact area equal to or greater than the cross-section area of the rail. The cable used, which is 800 000 cir. mils, is welded to the lower side of the flange of the rail, and a section cut through the weld shows a shading in color from steel at the top to copper color at the bottom of the weld. The cable enters the weld at the bottom and is therefore in contact directly with the copper film at the bottom of the weld, which insures minimum contact resistance. We are using this method of bonding on all reconstruction work.

The opinions here expressed are overwhelmingly in favor of bonding around special work. In several answers no mention is made of bonding the individual members of the special work. Although they are called upon to carry current only when a car is passing over them, it is obviously good practice to provide for at least light bonding to the main return circuit.

Although the consensus of opinion seems to be in favor of welding or brazing bonds to manganese steel, a number of engineers are apparently having good results from the bonds installed in the soft plugs provided by the steel companies. Only one answer refers to the possibility of injuring the manganese steel by welding bonds to it. Experience, however, seems to be sufficiently complete to show that any fear regarding such injury is unwarranted.

(*h*) Bonding of Converted Steam Roads.—The bonding of steam railroads in preparation for electrification presents some problems somewhat different from those obtaining on the ordinary city or suburban track. The conditions which are, as a rule, similar, are briefly as follows: (1) Joint plates are in place and the removal of them would not only be expensive but unsafe with the passing of high-speed trains; (2) the location is usually such as to invite theft of exposed bonds; (3) safety is of prime importance, and the adoption of any bonding method from which a broken rail might possibly result could not be permitted.

These conditions have forced several railroads to the adoption of a special type of bond which, so far, has been confined to this class of work. The objection to the removal of joint plates excludes the concealed type of bonds and necessitates the use of either a short bond or one long enough to span the plates. Objection has been made to the short head bonds both on account of the breakage of the strands and ribbons under heavy traffic as well as to the alleged injury done the rail by the welding heat and the drilling of the head. As the adoption of a long exposed bond would mean continual loss and trouble from theft, a long compressed or pin terminal bond has been devised and adopted by several railroads which can be inserted under the joint plate and locked in position by the removal of a single bolt. This bond

is provided with one terminal attached and one detached, and a sharp crimp or loop is put in the body of the bond near the end containing the fixed terminal. One of the end bolts of the joint plate is removed and the bond is threaded under the plate from this end. When the bond is in its proper position the bolt is replaced, which engages with the loop and locks the bond. The loose terminal is then soldered to the end of the bond and expansion or compression of the terminals is then affected in the ordinary manner. It is stated that in the electrification of the Chicago, Milwaukee & St. Paul Railroad this type of bond will be used and that it was adopted only after an exhaustive study of the subject. The Pennsylvania Railroad and the New York, New Haven & Hartford Railroad are also using this or similar types.

(*i*) DOUBLE v. SINGLE BONDING.—The proper size and number of rail bonds per joint appears to be a subject regarding which very little definite knowledge exists, and the present practices of the operating companies seem to be based upon arbitrary and irrational rules rather than upon theoretical considerations.[1] W. A. Del Mar, in a letter published in the Electrical World of April 1, 1909, comments upon the absence of information and standard practice upon this point, and gives the following four rules as having been used by the operating companies to determine the capacity of bonds:

(1) Making the conductor equal in capacity to the rail.
(2) Asking advice of manufacturers.
(3) Doing what other people have done.
(4) Guessing.

Realizing the irrational character of these rules, Mr. Del Mar attempted to determine the proper capacity of bonds by the following three more logical considerations:

(1) Determine the magnitude of the continuous and maximum currents in the rail and make the bond large enough to prevent undue heating.

(2) Make the bond large enough to give at least 90 per cent efficiency to the return circuit; that is, make the conductance of the bonded rails at least 90 per cent of the conductance of a

[1] The Bureau of Standards is now making preparations to conduct experiments on the carrying capacity of different types of bonds under various conditions. The results of these experiments will be published at a later date.

theoretically continuous rail. The following equation is given by Mr. Del Mar for the efficiency of the return circuit:

$$\text{Eff.} = \frac{L_1}{L_1 + \frac{L_2(1-K)}{K}}$$

where K = average efficiency of bond, or the ratio of the conductance of the bond to the conductance of an equal length of rail.

L_1 = length of rail,

L_2 = length of bond between terminals.

(3) Make the bond large enough to conform to proper mechanical conditions.

The author of the letter states that he was immediately frustrated in his attempts by having no data on the capacity of bonds, and after a thorough search through trade literature and scientific abstracts he came to the conclusion that no work was available as to the amount of current that short bonds would carry under various conditions without undue heating. He suggests this as a splendid field for research by the colleges and commercial laboratories and scores the manufacturers for not having data on the capacity of their various bond products.

That this subject is of immediate and practical interest, and one on which a great diversity of opinion exists, is shown by the following answers submitted to question E–W–88, asking for the practice of the companies regarding single and double bonding, published in the June and July issues of the A. E. R. A.:

C. D. Emmons, General Manager, Chicago, South Bend & Northern Indiana Railway Co., South Bend, Ind.—We single bond our track in all cases excepting in city streets where leading to power stations.

H. F. Merker, Engineer Maintenance of Way, East St. Louis & Suburban Railway Co., East St. Louis, Ill.—Where the return current is large and where a bad electrical joint would be serious, or where paving conditions make the opening of joints a serious matter, there is no doubt that double bonding is to be preferred. Remember the old maxim, "Do not carry your eggs all in one basket."

John Leisenring, Signal Engineer, Illinois Traction System, Springfield, Ill.—This company has adopted the practice of double bonding all track in pavement or other forms of streets. The tracks on private right of way are only single bonded.

H. P. Bell, Electrical Engineer, San Francisco-Oakland Terminal Railways, Oakland, Cal.—We practice both double and single bonding of rails, depending upon the current density, allowable voltage drop, size (conductivity) of rail, and capacity of bond.

Charles E. Fritts, Electrical Engineer, Metropolitan Street Railway Co., Kansas City, Mo.—Double bonding.

A. H. Babcock, Consulting Engineer, Southern Pacific Co., San Francisco, Cal.—Tracks are both single bonded and double bonded, according as the load requirements change with varying localities. No hard and fast rule can be laid down, but bonding should be done always with reference to the potential gradient in the rail.

A. V. Brown, Engineer Maintenance of Way, Lake Shore Electric Railway Co., Sandusky, Ohio.—Double bond all tracks in pavements.

Edward J. Blair, Electrical Engineer, Metropolitan West Side Elevated Railway Co., Chicago, Ill.—it is our practice to single bond our tracks, but this is rather a matter for local conditions to determine. Whenever the resistance of the return circuit can be kept within bounds by single bonding, it should be done.

C. L. Cadle, Electrical Engineer, New York State Railways, Syracuse, N. Y.—The practice of this company has been to bond each joint with at least one 4/0 bond. At locations where the current density is such that the size of this bond will not carry the current imposed on it, as high as five bonds are installed at each joint to take care of the additional current.

H. A. Clarke, General Manager, Ithaca Traction Corporation, Ithaca, N. Y.—I would state it is the practice of this company to single bond our tracks.

George L. Wilson, Engineer of Maintenance of Way, Minneapolis, Minn.—The Twin City Lines use only single bonds. It has never been the practice of this company to double bond its tracks.

H. G. Throop, Superintendent Line and Buildings, New York State Railways, Syracuse, N. Y.—It is a good practice to double bond tracks which are heavy carriers of return current to the power house from congested districts and also to double bond in congested districts. In both Utica and Syracuse this practice is followed throughout the central portions of the city and on lines to which the greatest amount of negative cables, which lead back to the power houses, are attached. This method also gives some insurance for good bonding, as of course the two bonds give greater life than a single bond.

George H. Pegram, Chief Engineer, Interborough Rapid Transit Co., New York, N. Y.—We double bond our rail joints.

H. E. Gough, Engineer, Elmira Water, Light & Railroad Co., Elmira, N. Y.—We double bond our tracks in the central portions of the city and where traffic is heavy. In outlying sections single bonding is used. We are using a pin-terminal bond for this purpose.

J. B. Tinnon, Engineer Maintenance of Way, Chicago & Joliet Electric Railway Co., Joliet, Ill.—We single bond tracks except where the return flow is very high, and then we double bond. The practice of double bonding for the purpose of having one good bond in case the other fails is, I think, a waste of money, as the same condition that causes one bond to fail will also cause the other to fail in most cases.

J. C. Donald, General Superintendent Asheville Power & Light Co., Asheville, N. C.—Bonding both track rails with cross bonds located every 200 feet is considered good practice.

F. M. Richards, Electrical Engineer, Atlantic Shore Railways, Kennebunk, Me.—It has been our practice to single bond our tracks, installing cross bonds between rails every thousand feet.

These answers throw absolutely no light on the question as to just what is the safe carrying capacity of rail bonds. That a short copper bond attached to heavy masses of cold steel can not attain a dangerously high temperature is obvious even when carrying currents of the magnitude found on heavily loaded tracks. The contact resistance of one terminal of a mechanically applied bond in good condition is in the order of 0.000005 ohm. When carrying a current of 500 amperes, which is greatly in excess of currents ordinarily found in rails, there would be a dissipation of only 1¼ watts, and with 1000 amperes a dissipation of 5 watts per terminal. This is, of course, in addition to the heat generated in the copper of the bond, but as far as the contact is concerned there seems to be no practical limit to its capacity to carry current.

Parshall in England, in an article on "Earth returns for electric tramways," published in the Journal of the Institution of Electrical Engineers, April 28, 1898, stated that experience with pressure contacts in central station work had demonstrated that 100 amperes per square inch was the safe limit, but suggests that 50 and even 25 amperes per square inch would be found more advisable for rail bonds. As these figures are exceeded in practically all installations in this country they can not be regarded in any way as a practical limit for current density.

A reference to the above answers will show that a number of companies, including some in large cities, install only single bonds and that several employ double bonding only when necessary to reduce the potential gradient on the tracks. This would indicate that double bonding is not necessary solely from the standpoint of capacity, but that its adoption is demanded by other considerations. One of the usual causes for its use is to insure safety, and not place reliance on a single bond in a permanent track where the repair of a bond would mean tearing up the pavement.

Under extreme conditions double bonding is justifiable solely from the economic standpoint, and the factors which determine these conditions may also be used to determine the economic

replacement of deteriorating bonds. These conditions can be determined when the constants of a given system are known and the cost of power and the average current in the rails are obtainable.

Let W = weight of rail per yard,

I = root-mean-square current in rail over a 24-hour period,

p = cost of power per kilowatt hour in dollars,

P = cost of installing a bond,

n = number of years bond will last,

L = reduction in joint resistance resulting from installation of bond, expressed in feet of adjacent rail,

r = rate of interest paid on invested capital;

then the resistance of the rail is very close to $0.001/W$ ohm per foot and the annual saving of energy in dollars due to installing a bond would be $I^2 \times \frac{0.001L}{W} \times \frac{p}{1000} \times 24 \times 365 = \frac{0.00876 I^2 Lp}{W}$

The annuity [2] required to retire the investment, P, on a new bond at the end of n years, its period of usefulness, is

$$P\left(\frac{R-1}{R^n-1}\right) \text{ where } R = 1 + \frac{r}{100}$$

When the annual power loss without the bond exceeds this annuity, it is obvious that the installation of a new bond would be a matter of economy. The limiting condition would be obtained when the energy charge is equal to the annuity. Equating these two we get: $0.00876 \frac{I^2 Lp}{W} = P\left(\frac{R-1}{R^n-1}\right)$, from which any quantity may be obtained provided the others are known. If we employ the equation to determine at what current double bonding becomes economical, we have

$$I^2 = \frac{WP}{0.00876\, Lp} \times \frac{(R-1)}{R^n-1}$$

In order to apply this equation with six independent variable factors it will be necessary to assume a set of values which would obtain under normal conditions.

[2] American Handbook for Electrical Engineers, p. 830.

Let it be required to determine whether one or two 4/0, 10-inch compressed-terminal bonds should be used on 100-pound rails being newly installed under the following conditions:

p = cost of energy = \$0.01 per kw. hr.
P = cost of installing bond = .60
n = life of bond = 12 years.
r = rate of interest = 5 per cent

The resistance of one 10-inch 4/0 bond, including contact resistance, is very close to 0.000055 ohm, and would probably average more. Two such bonds in parallel would have approximately one-half of this, or 0.0000275 ohm, which is also the decrease in the resistance of the joint resulting from the installation of the second bond. As a 100-pound rail has a resistance very close to 0.00001 ohm per foot, L would be 2.75 feet.

Substituting these values in the above equation we find that I^2 is equal to 15 660 or $I = 125$ amperes.

The Bureau of Standards has examined numerous railway load curves and has found that the ratio of the root-mean-square current to the all-day average, ranges from 1.25 to 1.4. If we use the lower of these values, which is more applicable for the heavily loaded lines with which we are concerned in this discussion, we get 100 amperes as the all-day average value of the current. With a load factor of 40 per cent this would give 250 amperes per rail as the value at the peak period.

While the values here assumed are normal in every respect, they are undoubtedly on the side tending to make the limiting current small. A lower cost of energy, a shorter life of the bond, and a higher cost of installing a bond will all tend to give a larger current where double bonding becomes economical. As the values assumed for these three variables are obviously near the limit in the other direction, it is difficult to conceive how the economy point would be reached at any all-day average current value much less than 100 amperes.

While a current of 100 amperes all-day average is entirely possible and undoubtedly exists on the rails of many properties, it is far in excess of what good electrolysis conditions would dictate. One hundred amperes on a 100-pound rail would give a drop of 1

volt per 1000 feet, and as 0.3 to 0.4 of a volt per 1000 feet, average for the 24-hour period, is considered the limiting potential gradient, consistent with good electrolysis conditions, it is seen that the latter condition would limit the current in the rails long before economy would demand double bonding.

It is true that double bonding will reduce the potential gradient in rails, and several of the engineers quoted above seem to consider this as a determining factor for this practice. Its influence in this respect is quite small, however, as will be seen from the following calculations:

Consider 10-inch 4/0 concealed bonds on 100-pound rails as before. With 60-foot rails we have approximately 59 feet of rail in series with the bond and the resistance of the two are 0.00059 and 0.000055 ohm, respectively, or a total of 0.000645 ohm. Adding a second bond would reduce the resistance by 0.0000275 or to 0.0006175 ohm, which is 95.73 per cent of the resistance of the rail with one bond. With 30-foot rails the effect would be more marked, and the maximum effect on the potential gradient resulting from the addition as a second bond would be where a short-head bond is installed on a joint previously bonded with a long-cable bond around the joint plates.

A 30-foot rail bonded with a 36-inch 4/0 compressed terminal bond will have a resistance made up as follows: 27 feet of rail, 0.00027 ohm, 3 feet of 4/0 copper, 0.00015 ohm, two contacts, 0.000013 ohm, or a total of 0.000433 ohm, of which 0.000163 ohm is due to the bond. If now a 4/0 electric-weld bond having a resistance, including contacts, of 0.000045 ohm be applied to the head of the rail the long bond will be shunted by approximately 2½ feet of rail in series with the short bond or by 0.00007 ohm. The two bonds in parallel will have a resistance of 0.0000487 ohm, making the resistance of one rail length of circuit 0.0003187 ohm, which is 73.6 per cent of the resistance before the application of the second bond. With 80-pound rails, 60 feet in length the corresponding figure would be 87.3 per cent.

These calculations will substantiate the statement that, except perhaps under extreme conditions, double bonding in lieu of single bonding has only a secondary effect upon the potential gradient in return circuits and therefore upon electrolysis condi-

tions. When the potential gradient therefore begins to approach the maximum allowable limit, or the limit set by good practice, other and more effective means should be employed to reduce it.

In all of the above calculations the effect of the joint plates has been neglected. Their effect would be to increase the conductance of the joint and therefore reduce the necessity of double bonding.

Considering only tracks in which the potential gradient does not greatly exceed the values considered safe from the standpoint of electrolysis we find that neither carrying capacity, economy, nor voltage drop will justify the practice of double bonding under ordinary conditions. The only factor remaining, therefore, which might justify the use of two or more bonds is that of insurance against the total failure of a bonded joint.

It is difficult to say to what extent the probability of a joint failure is reduced by the addition of a second bond. If the failures are the result of loose joints the second bond is not much of an insurance, while if failures are the result of imperfect workmanship in installation the value of the insurance is much greater. It is altogether possible that two bonds of different types could be used to advantage for this purpose rather than bonds of the same type. A long bond around the joint plates might act as an insurance against the failure of a concealed bond and a concealed bond might insure the joint against theft of the exposed type. In employing a second bond as an insurance against the total failure of a joint it, of course, acts to improve operating and electrolysis conditions as well, to say nothing of reducing the power loss in the return circuit. These advantages when considered together will ordinarily justify the use of the second bond on new and permanent tracks which are being installed in paved streets, where inspection of bonds is difficult and repairs expensive. The additional expense of installing the second bond at the time the new track is being laid is relatively very small and, in general, will be returned in reduced maintenance costs. The practice of double bonding would, perhaps, not ordinarily be justified on open track where the inspection and repair of bonds is less expensive and where the traffic as a rule is lighter.

(*j*) Economic and Other Considerations for the Replacement of Bonds.—The installation of a bond on a joint already bonded may be considered either as a replacement or as double bonding, and no sharp line of distinction between the two conceptions can be said to exist. The term "double bonding" has been used with reference to joints on which two bonds are originally installed or where a second bond is installed to supplement a new or old bond in a practically perfect condition. The term "replacement" will be used with reference to bonds installed to supersede or supplement old bonds which have failed or which are in a state of deterioration.

The value of the resistance which a deteriorating bond must reach before economy will justify its replacement can be determined from the equation given on page 98 of this paper, in which the reduction in the joint resistance resulting from the installation of the new bond becomes the unknown quantity.

Transforming the equation for this purpose we find that

$$L = \frac{WP}{0.00876\, I^2 p} \times \left(\frac{R-1}{Rn-1}\right)$$

The following concrete example will illustrate the application of this formula. Let us assume:

W, the weight of rail per yard = 100 pounds.
P, the cost of replacing a bond = $0.80.
p, the cost of energy = 0.0050 per kw. hr.
n, the life of the new bond = 10 years.
r, the rate of interest = 5 per cent.

Let us also assume that the current is of such a value as to give a drop of 0.8 volt per 1,000 feet as an all-day average on a perfectly bonded rail. This is greatly in excess of the current permitted by good electrolysis conditions and is not ordinarily exceeded, even in regions where the problem of electrolysis does not exist. The resistance of a 100-pound rail is 0.01 ohm per 1,000 feet, which would limit the average current to 80 amperes. Taking 1.3 as the ratio between the root mean square and the all-day average current we get for our equation $I = 104$ amperes.

The replacement cost of a bond is usually greater than the cost on new work and is therefore taken at 80 cents. One-half cent

per kilowatt-hour for power may seem low, but as it is assumed to be the cost of energy which will be saved by the application of the bond, it would not be logical to load it with fixed charges and operating costs other than the fuel. Upon this basis it is high rather than low.

A replacement bond is often installed on old track which is partially worn out and which may be entirely replaced within a few years. Ten years, therefore, is considered as a liberal life for the new bond. The srcap value of bonds is small and is neglected in this discussion.

Substituting these values in the above equation we find that $L = 13.4$ feet. As the new bond itself will test equal to from 3 to 6 feet of rail this means that the old bond will test equal to about 18 feet of rail before a new one can be installed with economy. This is, of course, far beyond the point of deterioration which good practice has established for the replacement of bonds. Electrolysis and voltage conditions ordinarily, therefore, demand a better return circuit than economy itself can dictate. In fact, it is doubtful if economy alone in many circumstances will justify any but the cheapest and simplest type of bonding. The Bureau of Standards [3] and numerous independent investigators have demonstrated beyond a doubt that the character of most electric roadbeds is such as to shunt a large fraction of the current from the rails even when well bonded. With poor bonding the increased gradient along the track tends further to increase the leakage current which might easily reach a large per cent of the total current, except in the immediate vicinity of the negative bus. Parshall, in an article previously referred to, makes the following statement:

> In tests recently carried out in a line some 8 miles long it was found, by cutting the track at the middle of the line and inserting an ampere meter, that some 60 per cent of the current was returning through the earth itself. Tests made as to the conductivity of the earth return showed as a whole that it was about one and a half that of the rails, bonds, and fishplates, which would indicate that on an average about 33 per cent of the current was leaving the rails. In other words, the voltage drop in the earth return was but two-thirds of what it would have been had the current been wholly in the rails.

[3] The Bureau of Standards is now engaged in investigating the resistance of different types of roadbeds under various weather conditions. Tests are being conducted on experimental tracks built for this purpose as well as upon city and suburban lines. A full account of this work will be published at a later date.

In this connection the experience of the Virginia Railway & Power Co. is of interest. They report that several years ago the bonds on an alternating-current line of several miles in length were failing rapidly as the result of incorrect methods and poor workmanship on the original installation. A complete rebonding of the tracks meant a heavy expense which the road at that time was not prepared to meet. A careful study of the situation was made and after ascertaining that bonds were being omitted on a number of modern European alternating-current lines it was decided to continue operation without rebonding and to keep a careful record of the energy consumption from year to year. After three years of this practice, during which time practically all of the original bonds had failed, the road is in successful operation and no increase in energy consumption chargeable to poor bonds has been noted.

Such a condition as here described would, of course, be utterly impracticable on an ordinary direct-current system on account of the pernicious electrolysis conditions which would obtain, to say nothing of poor operating conditions.

The one thing which calls for and demands good bonding is good electrolysis conditions. Without the incentive to guard against trouble from this source it is difficult to say to what degree of deterioration a company is justified in allowing its return circuit to descend.

(*k*) STANDARDS FOR REPLACEMENT.—The practices of the companies regarding the replacement of bonds, as recorded in Table 1 on page 32, indicate a wide variety of standards, ranging from 3½ feet of rail to 27 feet of rail as the limiting resistance of joints. Among the answers there was not a single suggestion as to the manner in which any particular standard was established.

The selection of a standard for replacement should be governed almost wholly by local conditions. There are so many elements to be reckoned with that it is practically impossible to suggest a hard and fast rule that would be applicable under all circumstances. Even if such a rule or formula could be developed it would contain so many variable factors and qualifying considerations as to make its application impracticable.

Frequent objection has been made to the universally adopted practice of referring to the resistance of a bond in terms of a

length of adjacent rail. The practice is a convenient one but obviously irrational, as it gives no indication of the actual resistance of the bond unless modified by supplementary data. The length of the joint tested, the length of the bond, and the weight of the rail must be known before the resistance of the bond in ohms can be calculated. A logical standard of replacement should obviously include these several factors, which would, however, greatly complicate the simple rule now in general use. It has been suggested that the replacement resistance of a bond should be defined in terms of its increase in resistance over that of a similar bond newly and properly installed rather than in some arbitrary length of adjacent rail, but this also has its objections. The increase in the resistance of a bonded joint results from breaking of strands and ribbons, corrosion of terminals, and loosening and rusting of plates, thereby reducing their ability to aid the bond. With welded bonds the deterioration from corrosion of the contact is nil while with the long cable bonds its effect on the total resistance of the bond is far less than in short concealed or head bonds. A standard therefore based upon, say, a 100 per cent increase in resistance, would be as irrational and arbitrary as one based upon a given length of adjacent rail. Moreover, with most of the standard bond-testing instruments, giving the resistance of a joint in terms of adjacent rail it would be difficult to discontinue the practice of referring to bonds in these terms.

A standard which is simple, definite, and workable, even though it does not always meet the demands based upon a rigid technical analysis of the subject, is much to be preferred to one which attempts to meet these demands but is clumsy, complicated, and impracticable. A standard of replacement based upon the resistance of a given length of adjacent rail possesses the advantages here enumerated and from the standpoint of practical considerations is not so irrational as may at first appear. After all, the factors which limit the resistance of bonded joints are, ordinarily, electrolysis and operating conditions, and both of these are determined by the potential gradient in the return circuit. If, therefore, we assume the same current density in rails of different weights, which is by no means a violent assumption, we are consistent in basing our standard on a given length of rail, inde-

pendent of its weight, thereby limiting the voltage drop across the joint rather than its resistance in ohms.

As to what this standard should be is a matter that should be determined largely by local conditions. Different standards might well be employed by a single company to meet the conditions on different types of construction or in regions requiring different degrees of electrolysis protection. It is altogether probable that it would be found advisable in some cases to employ different standards on city and suburban tracks. Answers to question 5 would indicate that the limiting resistance for a 3-foot joint of from 6 to 10 feet of adjacent rail would ordinarily fall within the bounds of good practice. Greater lengths might be employed in regions where no trouble from electrolysis is likely to exist, but on city streets these values should not be exceeded.

3. WELDED AND SPECIAL JOINTS

It has been previously stated that the information available relative to the life and character of different types of welded joints is far less complete than that upon the subject of rail bonds. Some of the reasons for this lack of reliable information are set forth in the following quotation from one of the prominent electric railway engineers of the country:

> In my experience I will say that I consider the information gotten from the furnished answers from questions as above to be unreliable. There are but very few cities in which the engineering department has been in existence or that the engineer has held his position long enough to be able to make any statement about worn-out rails or worn-out joints. The intensity of traffic and the weight of cars bears an important relation to the life of rails and joints and the conditions vary in different cities, and have varied so from conditions of 10 years ago that very few men are capable of intelligently answering the questions.
>
> Also the change in the material of which rails are made has been so great that unless this is considered the information is unreliable. The first Bessemer rails of a girder type were rolled about 1884. These rails were structurally defective, and the rail mill did not know how to roll the girder rail. Girder rails at this period weighed 56 pounds to the yard and were about 4½ inches high. By 1890 the girder rail had grown in height to 6 inches and some of the sections were such that they could be properly rolled, but many engineers were still using sections that could not get the proper treatment in rolling. About 1893 the 9-inch girder rail was coming into general use and girder rails commenced to be a success. The rails rolled from 1890 to about 1901 were Bessemer made from a good grade ore and gave a long life. About 1904 the grade of ore formerly used for making Bessemer rails was getting extremely scarce, so a lower grade was used, and for the next two or three years the rails furnished street railroad

companies were not as good as formerly furnished, and at this time the weight of cars had been materially increased, so that track life was short. About 1909 the open-hearth rail came into general use and apparently gives a very much better rail than that furnished previously, although the open-hearth rail has not been in use long enough to give absolute results on its life and durability.

The increase in carbon in the steel used in rails has materially affected the reliability of the welded joint in some locality.

Realizing as we do that the conditions here described are true to a large degree, we do not feel justified in attempting a close analysis of facts or in drawing any but the most cursory and general conclusions from the data and information at hand. The several types of welded and special joints will be taken up in turn and a brief summary of the facts available will be presented. Conclusions will be drawn and recommendations made only where the facts seem to warrant such.

(*a*) The Cast Weld.—The compilation of figures under question 1 on page 49 show that of the 268 052 electrically continouus joints reported, 149 716, or more than 50 per cent of the total, are cast welds. In consideration of the fact that the installation of this joint has been practically discontinued these figures are an indication of an early popularity at a time when the welding of rail joints was looked upon by many as a rather bold experiment.

The excellent results and long life obtained from this joint as reported by a number of companies, under questions 4 and 6, would seem to indicate that the discontinuance of its use in recent years is not the result of its inability to meet the conditions imposed upon it, but rather to the fact that other and more modern types of joints are meeting the requirements of service and installation in a more satisfactory manner.

Several causes are given as responsible for the failures of the cast weld. A frequent cause of complaint is that a true weld is not effected and the rails loosen up in the joint. This not only augments wear and cupping but adds materially to the resistance of the joint. Some operators are inclined to the view that the cupping of the rails at the joint is frequently due to the softening of the steel, which is said to result from the excessive heat of the molten metal. This is apparently the most serious fault that has been found with the cast weld and is no doubt largely responsible for the almost total abandonment of this type of weld which has

occurred in recent years. The large amount of molten metal used in the cast weld maintained the rail ends at a high temperature for a considerable length of time, and the slow rate of cooling had an annealing and softening influence which was later manifest in cupped and worn rail heads.

None of the modern welding processes employ the large amount of metal that was used in the old cast weld, and the cooling is consequently much more rapid. Moreover, the greatest heat is now confined to the web and base of the rail, and it is therefore extremely doubtful if the heads of modern steel rails are seriously injured by any of the welding processes in use at the present time. The cupping which so frequently develops in cast-weld joints may also have been augmented by a difference in the resilience between the joint and the adjacent rail or to imperfect surfacing, either of which would give rise to pounding and uneven wear on the rail.

In 1908 Parshall, in an article already referred to, has the following to say regarding the cast weld:

> Another method of somewhat the same nature as the process of welding is that known as the "cast weld," or the "Falk joint." This joint is made by pouring molten metal into a metal mold clamped round the rail joint. The surfaces of the cast metal that come in contact with the mold and with the rail joint are chilled, and are thus prevented from forming a perfect weld. I believe it has been asserted that a weld is effected. It seems, however, extremely doubtful, since without the use of a flux a weld is almost impossible between cold wrought steel and molten iron. The rail expands after the metal is poured around it, and remains expanded until after the cast iron has set, and finally resumes its former size. This affords a slight clearance for expansion and contraction, and accounts for the mechanical success of the joint, which, if carefully applied, makes when new a perfect mechanical track; although, in the writer's mind, the difference of resilience between the part surrounding the casting and the remaining part of the track may eventually cause uneven wearing away of the rail.
>
> The clearance above spoken of undoubtedly admits a certain amount of moisture, so that by the formation of oxide the resistance of the joint increases in the course of time. From the results of tests which I have at hand, it also appears that the electrical resistance of this joint, even when new, varies considerably; so that, considering the low voltage restrictions in this country, it should be used in connection with an efficient form of bond. Owing to the rigidity of the joint, however, copper bonds will undoubtedly be found more durable in conjunction with it than with a fishplate form of joint.

(*b*) THE THERMITE WELDED JOINT.—The failures of the thermite weld and the rather large percentage of cupped joints which have been reported from time to time have been for the most part on

the old type of weld and should not be considered as evidence against the greatly modified and newer joint which is referred to on page 20. Very little evidence is at hand regarding this modified type of weld, but if it is successful in preventing the cupping of the joint one of the chief objections to the thermite weld will have been removed. In contrast to the old cast weld the thermite weld requires but a small amount of welding metal, and this metal actually unites with the steel of the rail to obliterate the joint. The small amount of metal and the perfect union contribute to give the joint a resilience practically the same as that of the adjacent rail, and the wheel is thereby enabled to pass without encountering a hard spot in the track. Moreover, the metal being continuous, the joint has a high conductance which does not deteriorate.

Among the objections to the thermite weld has been recorded the facts that the process is comparatively slow and that in repair work where it is necessary to insert a short length of rail to take the place of a badly cupped railhead two distinct welds are necessary where other processes require only a modification of a single weld. These conditions are said to make the process less satisfactory on old rail than for new work.

The San Antonio Traction Co. adopted the new thermite weld in the reconstruction of their tracks, which was begun in October, 1913. A full account of the work was given by G. W. Smith, engineer for the company, in a paper presented at the annual convention of the Southwestern Electrical and Gas Association, at Galveston, Tex., in May, 1915. Mr. Smith made the following remarks:

> We have made a total of 3000 welded joints on track laid with concrete roadbed, and since the tracks have been put in operation we have had two breaks in the rails. One of these occurred at a crossover in the fall of 1914 and the other near a bridge in the winter of 1914. The first welds were made in the winter of 1913, and these have been through two winters and one summer. The joint which broke near the crossover is in this lot. The joints which were put in in the summer of 1914 have been through one summer and one winter, and the joint near the bridge was in this lot. In so far as we are able to judge from our experience of the past 18 months, we are convinced that, from the mechanical as well as electrical standpoint, the best type of permanent construction is obtained by welding the joints in the rails and using steel ties in concrete.

As the new type of thermite joint has been in operation for only about two years, it is too early to form definite opinions regarding it. That it is an improvement over the earlier types, however, there seems to be no question. Reports from other companies who have adopted it or who have installed it on an experimental basis will be looked forward to with interest.

(*c*) THE ELECTRICALLY-WELDED JOINT.—The relatively small number of 11 697 electrically-welded joints which were reported in answer to question 1 is no indication of the extent to which this type of joint is being used at the present time. Its use is confined for the most part to large properties where the Lorain Steel Co. is installing it by contract in great numbers. It is being used largely for reclaiming old track where cupped joints are repaired by using a "dutchman" and extra-long splice bars. Four welds are required on such joints instead of three, and the expense and time is about one-third greater than for an ordinary joint. The popularity of this type of joint is due largely to the rapidity with which it can be installed and the consequent small amount of interference with traffic. The conductivity of the joint is 100 per cent or better, which is greatly to its advantage.

The Boston Elevated Railway Co. has several hundred miles of new and old track welded by this process, for which Harry M. Steward, chief engineer of maintenance of way, has only words of praise. He declares this to be the cheapest method he has found for reclaiming old track which is cupped and in bad condition. He says, further, that breaks are more prevalent in old than in new rails, and attributes this to the fact that old rails have strains in them which are sometimes responsible for the fractures which are developed with the welding heat. These fractures usually occur through one of the holes of the rails, and it is said that if new rails with no drillings are welded that no breaks would occur. In fact, Mr. Steward says that the failures on their new rails have been practically nil.

The Worcester Consolidated Street Railway Co. installed 7800 electrically-welded joints in 1902, which have given entire satisfaction. Few failures have occurred, and the most of these have been fractures through bolt holes.

Company 10 has used the electrically-welded joint on old rails with cupped joints which they wish to maintain for six or seven years. They do not advocate the joint on new work, as they believe the spot welding introduces strains into the web of the rail which are likely to cause subsequent failures.

A head-supporting splice bar has been developed and is used on the rail sections which have shown a tendency to fail from a depression of the head. This splice is shown in Fig. 10.

Summing up the evidence at hand we find that the electric-weld joint has been used in the past principally for the reclaiming of old and partly worn rail, and there only where comparatively large contracts have made the use of the elaborate equipment practicable. The joints have a conductance equal to or greater than the solid rail and are welded rapidly. Badly cupped joints are welded by using a "dutchman," extra-long splice bars, and four instead of three welds. The local and intense heating of the web introduces strains into the rail which frequently are the cause of fractures and breaks. Such failures are less frequent on new than on old rails, and particularly less frequent on undrilled rails.

The following information regarding this welding process has been prepared from statements submitted by the Lorain Steel Co.:

ELECTRICALLY-WELDED RAIL JOINTS.

The electrical welding of rail joints by the Lorain Steel Co.'s process is done exclusively by them under contracts entered into with railway companies. The Lorain Steel Co. furnishes all apparatus, material, and labor for welding the joints. The railway company supplies the necessary current for operating the welding equipment and prepares the track ready for welding. Where repair work on old rail is to be done, this consists of removing the paving around the joints to the bottom of the rail, the ties not being disturbed; removing the old splice bars and bond wires, and bringing the rail ends to the proper surface and line. New rail is welded either before or after the paving is done, a space being temporarily left around the joint in the latter case. After the welding is completed the railway company replaces the paving. Where traffic is not heavy the work can be carried on continuously, day and night. On double track portable crossovers are made use of by the railway company for diverting the traffic. In sections where the traffic density is too great to permit of the use of crossovers the work is done between the hours of midnight and 4 or 5 a. m. The portability of the welding equipment making it easy to weld in one place for a few hours and then move to some other locality. About 15 minutes are required to complete a joint. Three welds are made on the standard and head-support joints, and the current is on about 2 minutes for each weld. At 500 volts about 250 amperes are required,

or about 125 kw., this current being on for 6 minutes to each joint the power consumption amounts to about 12½ kw. hrs. per joint. The parts to be welded are brought to a welding heat by means of the resistance offered by the materials to be welded to a large flow of current under a low voltage. The current is used simply for heating and no arc is formed. The welding current is supplied at about 7 volts. After the proper degree of heat is attained the current is cut off and the parts are forced together under very heavy pressure which is held in place until the metal has cooled below the critical temperature of crystallization or recalescence.

The process is applicable to all kinds of track construction where the motive power to be used is electricity. In welding open track on elevated railways or on surface lines on private right of way, expansion joints are made use of to provide for expansion and contraction. These are placed from 800 to 1000 feet apart and at the ends of all curves.

A welding equipment consists of four cars, provided with railway motors, and is operated in three units. The first car contains a motor-driven air compressor and a sand-blast apparatus. With this the rails and bars, at the points where the welds are to be made, are entirely cleaned of dirt and rust. For the second operation of welding two cars coupled together are provided. The first of these cars carries the welding transformer and pressure apparatus suspended from a crane, in the car to the rear of this a rotary converter, inverted, changes the direct current from the trolley to an alternating current. A regulator maintains the welding voltage practically constant at 300 volts regardless of the fluctuations of the trolley voltage. A range of from 325 volts to 650 volts direct current can be operated on. The current from the regulator is passed to the welding transformer, and is here stepped down to the welding voltage, of about 7 volts with about 25 000 amperes. The bars are placed over the joint, one on each side of the rail web, and the welding contacts are brought into place to engage the middle of the bars, and this weld is made first, after which one end of the bars is treated and then the other end. In this way the bars are in an elongated state when the ends are welded and on cooling off exert a powerful pull to bring the rails ends together, thus leaving practically no joint at all. In the car carrying the rotary converter a switchboard carries instruments for recording the voltage and amperage. In the welder car suitable water tanks and circulating system is provided for circulating water through the welder transformer and the contacts to keep them cool. The third operation consists of grinding the head of the rail to a true running surface, and the last car carries suitable grinding machines for this purpose. This car also carries a furnace for melting the spelter used in making the head-support joint. The cars have been so designed that they can be readily loaded on gondola freight cars and are shipped from city to city in this manner.

Where it is necessary to ship the equipment by railroad the company requires 3000 or more joints to make it justify them in taking a contract, but where the machines can be run over trolley tracks they accept work for as few as 500 joints.

(*d*) THE ARC-WELDED JOINT.—The application of the electric arc to the welding of rail joints is comparatively recent, and although numerous companies have installed a few arc-welded joints as an experiment, many of these have not been in service long enough to afford reliable information as to their ability to meet the demands of service. Moreover, the arc has been used

in the construction of so many different types of joints that time alone will be able to determine their relative merits.

Special plates as shown in Figs. 11 and 12 are manufactured by the Indianapolis Switch & Frog Co. and have undergone several changes and improvements during recent months. Formerly the ends of these plates were brought to points instead of being cut off as shown, and this brought two welding seams to a juncture at the base of the web. With a similar plate applied on the opposite side of the rail two more seams were brought to the same region. This condition resulted in numerous breaks through the base of the rail and led the company to adopt the modified form of plate here shown. Not only have the plates been cut off to prevent the juncture of the welding seams but one plate is made slightly higher than the other, and they are then staggered longitudinally. The result is that no two seams come directly opposite each other and the rail at no point is heated by more than one seam. It is claimed by the manufacturers that these modifications have greatly reduced the possibility of failures from fractures.

The following information regarding this welding process has been prepared from statements submitted by the Indianapolis Switch & Frog Co.:

ARC-WELDED PLATES.

A general view of the welding outfit as manufactured by the Indianapolis Switch & Frog Co. is shown in Fig. 19. This welder, which consists largely of resistance coils to reduce the potential at the arc to about 70 volts, is mounted on light wheels similar to those of a wagon, weighs 1700 pounds and costs $500 f. o. b. cars at Springfield, Ohio. One man can place this outfit alongside the track and perform the welding without interruption to traffic, but a helper is usually provided to remove the trolley pole for passing cars and to assist generally in the work. The operator himself should be a man of intelligence, initiative, and ingenuity, and is usually paid from $2.50 to $4 per day. The current strength required is from 150 to 180 amperes and the time necessary to weld a joint is variously reported at from 30 minutes to over 1

hour. The energy consumption, therefore, based on 175 amperes and a time of 45 minutes is 72.2 kw. hrs. per joint on a 550-volt circuit.

The Simplex joint plates, shown in Fig. 11, cost from $1.95 to $2.25 and the Apex type of plates, shown in Fig. 12, from $3 to $3.50. The welding steel, which is supplied in various grades by the company to meet different requirements, is relatively a small item.

Where it is necessary to maintain traffic over joints which are being welded, the plates are held in place by two bolts temporarily installed instead of by the clamps shown in Fig. 19. In order to reduce the liability of overheating the rail in any one place the following instructions have been issued by the company to all purchasers of plates:

In case of old rails, remove rust, grease, pitch or moisture, using an old file or wire brush, and, if necessary, the carbon arc.

Spot each end of each plate, first on the base line, then on the top line, for a distance of about 1 inch, to insure holding the plate in position and to resist the tendency to kink or creep during welding.

Run a heavy fillet of steel around edges of plates, drawing a pocket or cavity in both the edge of the plate and the rail. This is important. At the same time deposit a globule of the molten electrode, filling in the cavity and building up at least one-fourth inch.

Weld plates as follows (refer to Figs. 11 and 12): (*a*) Weld on base line from each end to center; (*b*) weld opposite plate the same; (*c*) return to the first plate and weld from the base upward on the sloping cut on each end of the plate; (*d*) weld both ends of opposite plate in similar way; (*e*) return to first plate and weld along top of plate, beginning at the end and welding to the center; (*f*) weld top of opposite plate in same manner; (*g*) do not attempt to weld across the undercut at ends of plates, as the point is cut off to prevent joining the two lines of welding.

Some companies are welding standard fish plates or angle bars to the base and head of the rail, while still others are using bolted or riveted joints and welding only the base, such modifications being designed principally to overcome the objection to heating the web of the rail.

That the use of the arc-welded plates is justified from the mechanical standpoint alone is shown by the fact that they are being used successfully in Cincinnati, where the double-trolley system makes rail bonding unnecessary. F. J. Venning, superintendent of construction for the Cincinnati Traction Co., states

that standard plates are used for this purpose and that they are welded along the head of the rail and to a plate or shoe placed under the base of the rail. The joint costs about $4 and is said by Mr. Venning to be cheaper and better than the continuous joint. Incidentally, Mr Venning states that the company is making most of its frogs and special work, using old rails and the arc welder for the purpose, and is saving as much as 50 per cent on some jobs.

The Dayton, Springfield & Xenia Southern Railway Co. is using the electric arc to weld their rail joints to Abbott base plates. They also spot weld the nuts on the joints, which prevents them from working loose.

The Springfield Railway Co., of Springfield, Ohio, is introducing arc-welded joints on all straight work. Steel ties are used, and these are spot welded at all rail ends, thus affording good cross bonding. George C. Towle, general manager of the company, predicts that all city tracks will be welded within a few years, possibly including special work as well. He states that the manganese steel now being used will last from 10 to 15 years, and can therefore be welded the same as straight work, but that its high resistance will probably necessitate supplementary bonding.

The Ohio Electric Railway Co. installed a number of arc-welded joints in Springfield, Ohio, more than a year ago, and during the first winter a number of rails broke outside of the welds. A number of these breaks occurred on rails where the pavement had been completed on only one side and are therefore attributed to excessive contraction during the cold weather. It is also said that the rails have a particularly high carbon content, which might account for the high percentage of failures.

The Columbus Railway, Power & Light Co., of Columbus, Ohio, is using a special joint, which is illustrated in Fig. 20. Special plates, which hug the web of the rail with practically no clearance, are carefully bolted to the rails after reaming the holes for a driving fit. These plates are welded to the base of the rail, and a short section of a Carnegie steel tie is inverted under the joint and also welded to the base of the rail. E. O. Ackerman, engineer of way for the company, claims that this joint is not only eco-

nomically installed, but that it is giving excellent results, with no failures. He does not like the idea of heating either the head or web of the rail and believes that a head support is essential to best results. These features he has incorporated in the special joint here described.

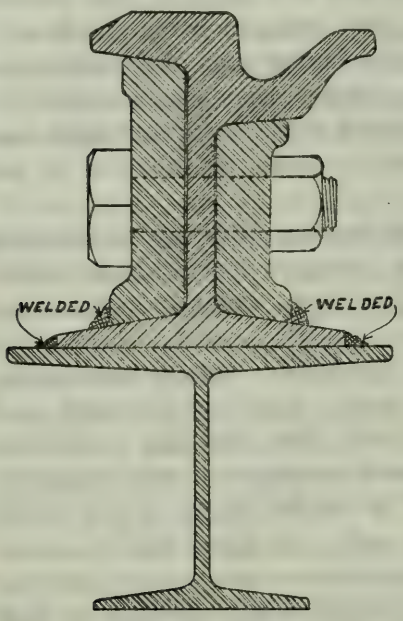

FIG. 20.—*Combination welded and bolted joint used in Columbus, Ohio*

The Butte Electric Railway Co. is using the electric arc to repair all broken thermit welds and also to some extent on regular construction. They are not afraid to heat the head of the rail as is shown in Fig. 21. In explanation of this figure the company says:

This drawing shows our method of welding this particular joint. With other types of rails and joints the manner is varied to suit the type. For instance, in welding a joint on a 52-pound T rail, angle and bolt joint, we use a welding plate which will be just wide enough to reach from the flange of the angle bar to the top of the rail, and we weld the plate to the top of the rail and to the angle bar. We use the carbon for melting or cutting down the rail ends at the joint, afterwards filling it up with steel. Of course, on this type of joint the angle bar can not be welded to the bottom of the rail.

This drawing does not show the longitudinal extent of the weld in the head of the rail at the joint, which is about 2 inches.

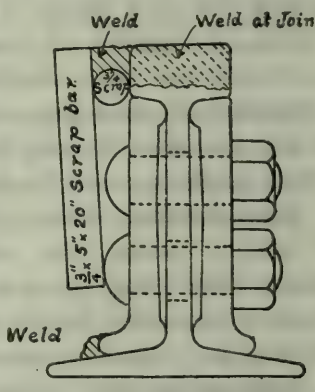

FIG. 21.—*Combination welded and bolted joint used in Butte, Mont.*

One of the principal objections which has been found to the arc-welded joint is that the process is slow, requiring about one hour per joint. However, as the welding can be done without interruption to traffic and requires the time of only two men this objection is not serious. The energy

consumed is considerable, but even when figured in at a liberal rate the total cost of a joint is lower than for most other types of welds.

(*e*) THE CLARK JOINT.—This joint, as used in Cleveland, and a modification of it as used in Baltimore, have been briefly described on page —. They resemble the special joint used in Columbus, Ohio, and shown in Fig. 20 in that they are a combination of a high-grade bolted joint and a welded joint, the thermit shoe shown in Fig. 22 taking the place of the weld on the Columbus joint.

This joint has been standard with the Cleveland Railway Co. since 1906, where 50,000 of them are in operation, and where only three failures have been recorded. The joint is said to cost from $4.60 to $5.

The modified Clark joint is standard with the United Railways & Electric Co., of Baltimore, where they report no failures up to the present time. The joint is said to cost from $7 to $9.

The Clark joint, or one similar to it, has also been installed in Buffalo. H. L. Mack, superintendent of tracks and lines of the International Railway Co., states that in installing these joints he bonded one rail leaving the other without bonds. Subsequent tests showed the unbonded joints to have an efficiency of from 60 to 70 per cent while the bonded joints showed about 90 per cent.

While the electrical efficiency of this type of joint is undoubtedly less than that of other fully welded types, it is of a permanent nature and no other form of bonding should be necessary.

(*f*) THE NICHOLS COMPOSITE JOINT.—This joint, which is described on page 22, has had rather a limited application, but has nevertheless met with excellent results in Philadelphia and St. Louis. Following is an extract from a letter from George B. Taylor, engineer of way for the Philadelphia Rapid Transit Co.:

> The Nichols composite rail joint was first used in this city in 1901, and since that time practically all of our 9-inch track has been equipped with such joints, and some of our T rail has also been so equipped; the total mileage at the present time being about 330 miles. All of the track constructed or reconstructed during 1914 had these joints applied, and we expect to apply the same during the coming season. We have removed practically none because of defects, but a small amount of track, constructed about 1902, and equipped with the Nichols joint, was removed a few years ago for the simple reason that the rail was worn out.

Over 8000 of these joints are in service in St. Louis where they report that no failures have occurred in the three years since their installation.

The joint is expensive and must be installed by experts who realize the necessity of careful work. Tests made in Philadelphia by the Bureau of Standards some years ago show that the conductivity of the joint is practically the same as that of the unbroken rail.

V. EXPERIMENTAL TESTS

During the course of its investigation of the subject of rail bonds and rail joints the Bureau asked a number of the manufacturers to submit samples of their products for experimental as well as for exhibition purposes. They very willingly responded and a number of bonded and welded rail joints were collected in this manner. These were all tested for conductance and a few specimens were tested by the department of metallurgy of the Bureau for the effect of heat on the steel.

The Bureau of Standards realizes that laboratory tests on individual specimens afford no definite indication of the value of the average bond or joint under service conditions and therefore wishes to caution against placing too much reliance upon the results here given. However, the specimens, as a rule, are normal and should give a fair idea of what should be expected of new bonds and joints of similar types. All resistances were determined by comparing them with a Leeds & Northrup 0.0001 ohm shunt, the comparison being made with a high-resistance Weston millivoltmeter. A current of about 200 amperes was used in all tests.

A description of the several bonded and welded joints tested and the results obtained are given in Tables 7 and 8. It is of interest to note that all of the bonded joints showed a much greater conductance with the plates bolted in place than when removed. Mention has already been made of the fact that tests on old unbonded joints show that a large per cent of them have a resistance greater than 1000 feet of rail and that this change in the conducting power of joint plates might easily have been mistaken in many instances for a deterioration of the bond itself.

TABLE 6

Resistance Tests on Bonded Rail Joints

[All resistances given in microhms, double contact resistance taken as the difference between resistance of joint across extremities of abutting rails and resistance of bond between terminals.]

	American Steel & Wire Co.'s bonds			Electric-weld bonds, Electric Railway Improvement Co.		Oxy-acetylene welded bonds	
	Compressed terminal	Pin terminal	Twin terminal	Head bond	Concealed bond	Prest-O-Lite head bond	Ohio Brass Co. head bond
Weight of rail (pounds)	80	80	80	65	65	90	80
Length of joint plates (inches)	34	34	34	24	24	26	.....
Number of bolts in joint plates	6	6	6	4	4	4	(a)
Capacity of bond	4/0	4/0	4/0	4/0	4/0	4/0	4/0
Circuit length of bond (inches)	10	10	8	4½	10	8	7
Distance on rail, center to center of terminals (inches)	10	10	3	3½	10	3½	3½
Resistance of 3 feet of joint, plates in place	(b)	43.8	34.9	62.2	66.7	37.1	.....
Resistance of 3 feet of joint, plates removed	92.7	80.1	74.5	84.5	79.9	75.5	68.9
Resistance across extremities of rail ends, plates removed	66.0	55.0	36.0	30.0	47.9	36.9	33
Resistance of bond, center to center of terminals	50.5	42.3	32.5	26.8	42.9	31.5	27.6
Double-contact resistance	15.5	12.7	3.5	3.1	5.0	5.4	5.4
Single-contact resistance	7.7	6.3	1.7	1.5	2.5	2.7	2.7
Resistance of 3 feet of joint in feet of adjacent rail, plates on	.....	3.65	2.91	3.29	3.56	3.37	.....
Resistance of 3 feet of joint in feet of adjacent rail, plates removed	7.73	6.67	6.21	5.83	5.48	6.83	5.85

[a] No plates. [b] Not taken.

TABLE 7

Resistance Tests on Welded Rail Joints

	Electrically welded joints, Lorain Steel Co.			Goldschmidt Thermite Co.'s thermite joint	Indianapolis Switch & Frog Co., arc-welded joint
	(1)	(2)	(3)		
Weight of rail (pounds)	109	122	100	104	70
Type of rail	Girder	Girder	T	Girder	T
Resistance of 3 feet of rail (in microhms)	27.5	24.6	30.0	27.0	37.56
Resistance of 3 feet of joint (in microhms)	20.4	20.4	21.6	27.3	27.18
Efficiency of 3 feet of joint (per cent)	135	120	138	99	138

At the request of one of the manufacturers the Bureau has attempted to determine what effect the heat, accompanying the welding of bonds or steel plates, has on the grain structure of the rail and to what depth a change in grain structure takes place. Several specimens were accordingly turned over to the metallurgists of the Bureau, who tested the hardness of the steel at numerous points by the Brinell test and also made microscopic examinations of the grain structure in and out of the "weld zone."

The Brinell test, which consists in measuring the penetration of a cylindrical steel point under a given pressure, showed no appreciable difference in the hardness of the steel in the "weld zone" and at other locations. However, as tests could not be made closer than about three-sixteenths inch from the edge of the steel by this method, it gave no indication of the hardness immediately adjacent to the weld.

Photomicrographs, together with the report of Dr. Merica, who made the examinations, are shown in the accompanying figures.

Fig. 23, with a magnification of about two diameters, shows a portion of the cross section of a rail after being etched, to which steel plates had been welded by the electric arc. Figs. 24, 25, and 26 show the grain structure close to the weld, at the edge of the weld zone, and in the center of the web, respectively. They are magnified to about 100 diameters.

Fig. 27 shows a portion of the head of a rail to which a bond had been applied by the oxy-acetylene flame and Figs. 28, 29, and 30 show the grain structure close to the weld, at the edge of the "weld zone," and outside of the weld zone, respectively. Fig. 31 shows a portion of the web of a rail to which a bond had been electrically welded, and Figs. 32, 33, and 34 show the grain structure close to the weld, at the edge of the "weld zone," and in the center of the web. Following is the report of Dr. Merica:

MICROSCOPIC EXAMINATION

Transverse sections of parts of the rail adjacent to the weld were polished and etched with alcoholic HCl.

That the structure had been changed by welding could be immediately seen by the fact that immediately adjacent to the weld the steel etched much more heavily. This is shown in photographs Nos. 322, 321, and 323 of specimens 855, 858, and 857, respectively (corresponding to Figs. 23, 27, and 31).

Upon microscopic examination of the structure within and near this "weld zone" it was seen that this zone represented that metal which had suffered grain growth or

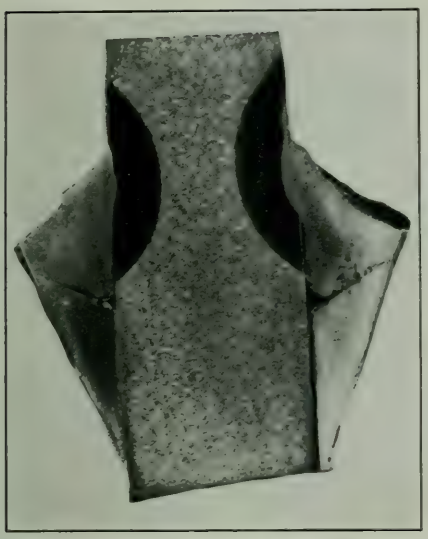

FIG. 23.—*Heat penetration in arc welding*

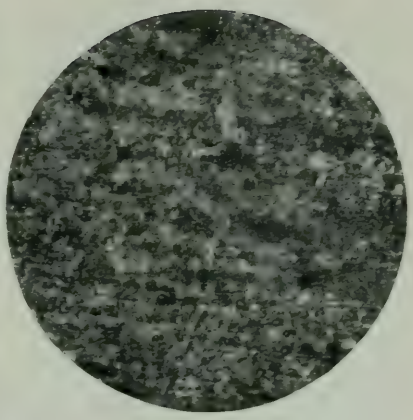

FIG. 25

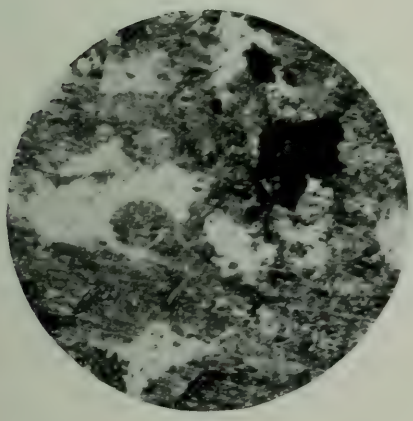

FIG. 24

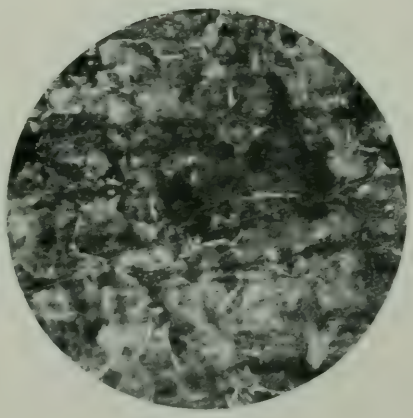

FIG. 26

FIGS. 24, 25, and 26.—*Photomicrographs showing grain-structure of steel after arc welding*

FIG. 27.—*Heat penetration in oxy-acetylene welding*

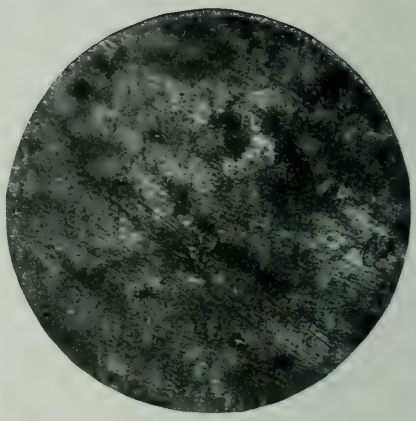

FIG. 29

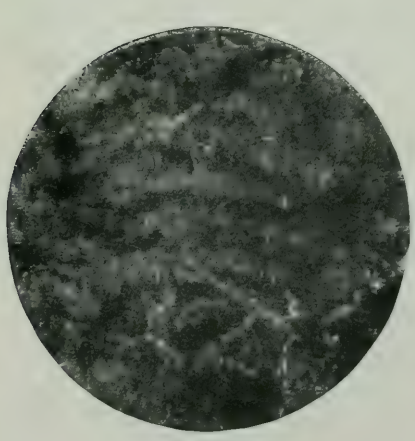

FIG. 28

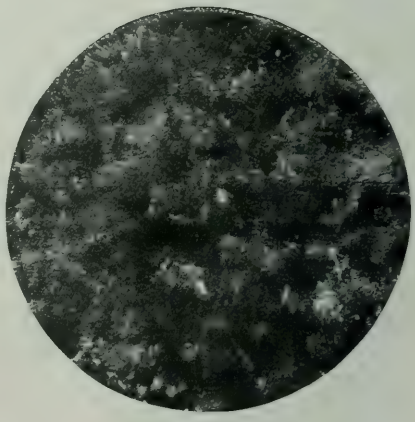

FIG. 30

FIGS. 28, 29, and 30.—*Photomicrographs showing grain-structure of steel after oxy-acetylene welding*

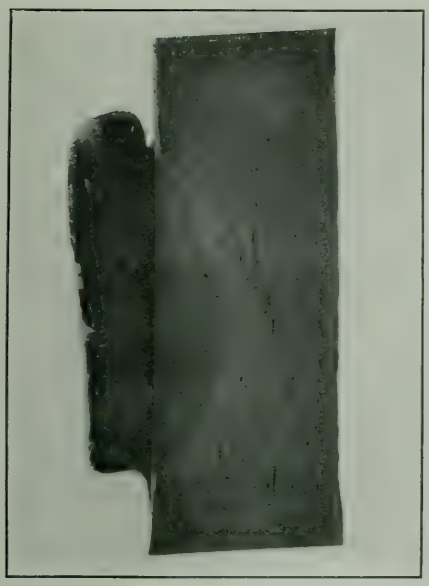

FIG. 31.—*Heat penetration in electric welding*

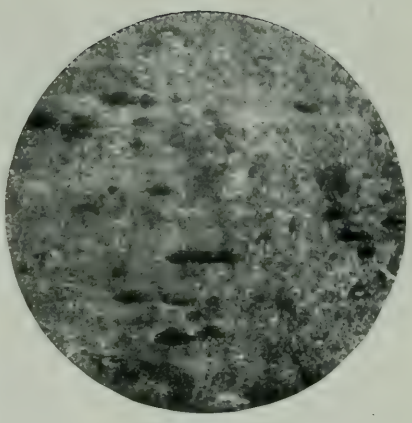

FIG. 33

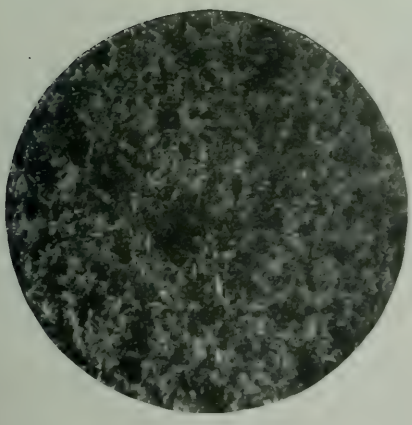

FIG. 32

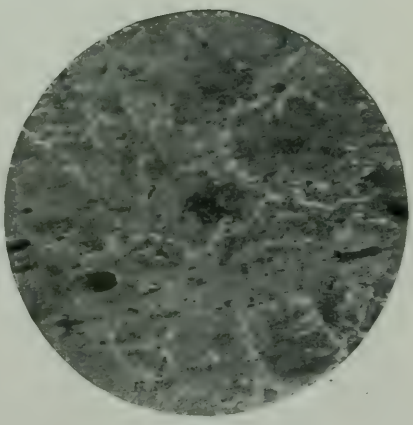

FIG. 34

FIGS. 32, 33, and 34.—*Photomicrographs showing grain-structure of steel after electric welding*

recrystallization. At the extreme edge of the copper (or steel) the metal had been heated above 700°, the transformation point, and had recrystallized, cooling rapidly to form a fine-grained structure. Near the edge of the zone the metal had been heated just under the transformation point and had merely undergone grain growth, as evidenced by the coarser structure at this point. Without this zone no change in structure had taken place. The zones vary in depth up to 0.8 cm.

This change in structure can not be considered serious from the standpoint of the wear of the rail.

VI. GENERAL CONCLUSIONS

Owing to the great number and variety of details involved in the foregoing discussions a complete summary of all data and conclusions will not be attempted. Attention, however, will again be called to some of the more important features of the subject under consideration.

Among the most important tendencies as revealed in the investigation is the attitude which the companies are now taking toward the whole subject of bonding. That it is an engineering problem deserving of as much skill and attention as any other problem in connection with the operation of an electric railway is apparently being realized by the large majority of the railway engineers. The testimony given herewith shows a marked tendency to get away from all types of soldered bonds which, even in recent years, have been installed in great numbers. A few companies who employ thoroughly experienced and careful workmen still continue to use them but the number is relatively small.

Practically all types of standard modern bonds, when selected to meet local conditions and installed according to the best modern practices, will give satisfactory results with an almost negligible percentage of failures on joints which are properly maintained. The problem of rail bond maintenance is largely that of joint maintenance. No bond can be expected to last continuously on a loose and poorly supported rail joint. No one type of bond can be said to be better than all other types. Each has its advantages and disadvantages and the selection of a bond for any particular service should be governed by the type of construction on which it is to be used, the grade of labor available for installation, and upon numerous other local conditions.

While welded joints are being used more than ever before there is also a growing tendency to adopt improved mechanical joints

and various forms of special joints, several of which are a combination of welded and bolted or welded and riveted joints. These special joints seem to be meeting the demands of service with less failures and better results generally than any of the standard types.

It has been demonstrated that the saving of power alone will not justify the best modern practice in bonding. Such practice, however, is justified and strongly recommended from the standpoint of good voltage conditions in the return circuit, which not only make for good electrolysis conditions but also for more satisfactory operation.

Attention is again called to the fact that the problem of track bonding is still in a state of evolution. New inventions and improvements in methods and practices have been so frequent during recent years that many types of bonds and joints can still be said to be in the experimental stage. Carefully kept records and a free interchange of experiences on the part of the operating companies will do much toward the establishment of definite and standard practice in this particular field.

In conclusion we wish to thank the many operating and manufacturing companies which have contributed the data and information contained in this paper. They include not only those whose names are formally recorded herein but many others, which, through personal interviews and correspondence, have rendered no less valuable assistance.

To Dr. E. B. Rosa and Mr. Burton McCollum, chief physicist and electrical engineer, respectively, of the Bureau of Standards, is due recognition for conceiving and outlining the scope of this paper, as well as for offering many invaluable suggestions regarding the collection and arrangement of the material which it contains.

Special thanks are due to C. S. Kimball, of the Washington Railway & Electric Co., who is also chairman of the committee on way matters of the American Electric Railway Association, and to Prof. Albert S. Richey, of the Worcester Polytechnic Institute, for reading this paper in manuscript and offering valuable suggestions for its final revision.

WASHINGTON, October 14, 1915.

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APPENDIX

[Comprising material additional to that in the 1915 edition]

NOTE.—Special attention should be given to the appendix in connection with the following subjects:

	Pages
Brazed or electric-weld bonds	15, 16, 83–86
Cast weld	19
Thermit-welded joint	20 and 108
Electrically welded joint	21 and 111
Arc-welded joint	112

Since the issue of this paper in 1916, there have been no important changes in the art of bonding and welding rail joints, although a number of improvements have been made in existing processes. One marked tendency has been toward the more general use of all types of welded bonds with the almost complete abandonment of soldered bonds and those mechanically applied to the head of the rail. Pin-terminal and compressed-terminal bonds are still extensively used for application to the web of the rail, but even here the welded type is finding favor with many companies. One reason for the increasing use of gas and electric weld bonds is to be found in the development of lighter, cheaper, and less unwieldy tools for their application. Some of the newer methods and apparatus which have been developed for this class of work are so far superior to those formerly employed that it seems appropriate to include a description of them in the second edition.

With the abnormal price of copper during the war period, the cost of long bonds became almost prohibitive and this also acted as a stimulus to the use of short head bonds. Although little new track work of a permanent character was done during the war, there has been some advancement in the welding of rail joints and the most important improvements in this field will also be described here.

(*a*) ELECTRIC-WELD BONDS.—A marked improvement over the bonding car shown in Fig. 6 and described on page 86 has been developed by the Electric Railway Improvement Co., and is known

FIG. 35.—*ERICO portable welder*

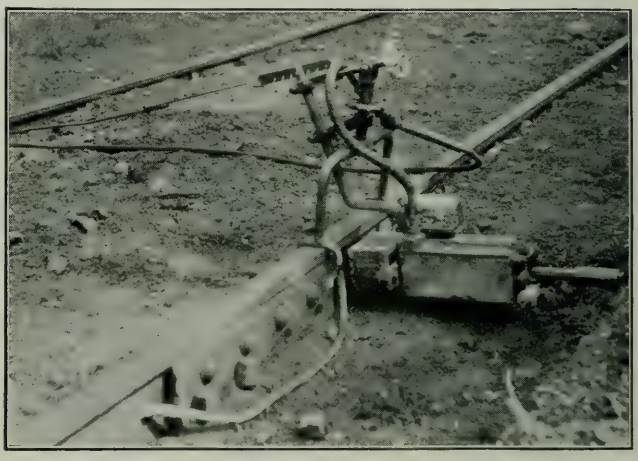

FIG. 36.—*Web welder*

as the Erico portable welder. It produces the same weld as was formerly obtained with the larger and more expensive car and in addition may be used as an arc-welding set for work either in the shop or along the track. The new apparatus shown in Fig. 35 consists of the welder proper and a rheostat, the combined weight of which is said to be less than 250 pounds.

The welder part of the equipment consists of an inclosed furnace box on the front side of which is inserted a graphite plate which is brought in contact with the rail bond terminal. This furnace box is surrounded with a magnetic winding, which is in series with the heating current. Through the center of this winding passes a carbon electrode which enters the back of the furnace box through a narrow slot and makes contact with the graphite front plate. The process of welding the bond terminal consists in establishing an arc in the furnace box between the carbon electrode and the graphite front plate which presses against the bond terminal. In producing the weld the arc does not come in contact with either the bond or rail, thus avoiding the danger of injury to the bond, rail, and eyes that such methods are liable to introduce.

It is claimed that the inclosed magnetic arc of the welder has a potential drop of about 125 volts and requires from 100 to 125 amperes; taking about one minute to weld a No. 4-0 terminal to the rail. The winding has the effect of focusing the arc directly on the front plate where the heat intensity is required.

The mechanical details of the welder are such that the apparatus is at no time attached to the rail; it can therefore be removed from interference with traffic by simply picking up and setting to one side. It is supported in operating position at two points on the rail to be bonded and by a hook reaching over to the other rail. Adjustment of the contact of the graphite front plate against the bond terminal is effected by varying the length of the hook and by raising or lowering the body of the welder by means of a vertical screw operated by a hand wheel.

The welder, as used for installing bonds underneath the fishplates and for attaching cables around the plates, is shown in Fig. 36 and weighs approximately 40 pounds.

Current is supplied to the welder directly from the trolley wire through a special portable rheostat, which is designed to secure a

wide range in current capacity, with the maximum radiating surface and the minimum weight of materials used. The rheostat is composed of a number of independent resistance units in parallel producing a range of from 60 to 200 amperes in 15 ampere steps. While this range in current is not required in the operation of the welder, it is quite essential in using the rheostat for general arc welding work. The weight of the rheostat is 140 pounds when equipped with flanged wheels for rolling along the track. It is not necessary to have the rheostat on the track while the welding process is performed—it may be set at one side of the track if desired.

The rheostat of the portable welder may also be used for installing arc-weld bonds to the rails by a method of welding which is and has been universally used for years in all kinds of arc-welding work.

The terminals of the rail bonds used in this process are provided with an iron casing, which is electrically welded to the copper in the process of manufacture.

The arc-weld bond is placed against the rail for welding and is so adjusted that a V-shaped space is produced between the rail and iron casing of the bond. This space is then filled with welding rod by means of the electric arc. The attaching of the ironclad bonds is therefore an operation similar to that with which all arc welders are familiar, and which any arc welder should do with ease, and one which an inexperienced employee may readily be taught.

The results obtained by welding iron to iron are said to be much more satisfactory than where copper is welded to iron owing to the tendency of melted copper to oxidize rapidly, thereby producing a spongy structure having little mechanical strength. For this reason, as well as on account of the greater economy, steel terminals or ironclad terminals are commonly used on gas and electric weld bonds.

Another type of electric-weld bond which has come into extensive use since the publication of the first issue of this paper is the L–V type of the Lincoln Bonding Co. This bond, illustrated in Fig. 37, is of the laminated, short, exposed type, being 6 inches in length and only 2½ inches between terminal centers. The weld-

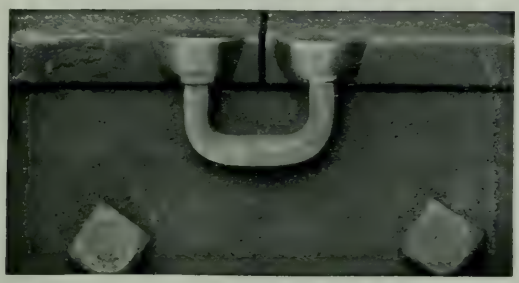

FIG. 37.—*4-0 Lincoln bond welded to rail*

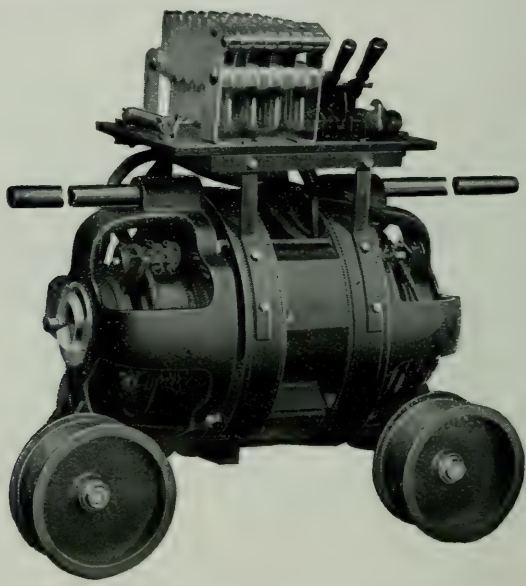

FIG. 38.—*Dynamotor for track bonding*

ing process is essentially different from other similar operations. The carbon-arc type of welding is used and the bond is held in place prior to and during the welding in a mold of carbon with a copper plate forming the base. An arc is struck and the head of the bond is melted down and allowed to run over the copper plate, after which No. 4 scrap copper is fed into the arc and a solid head is built up. An important feature in this welding process is the manner in which the arc current is generated and controlled. Instead of being supplied from the trolley wire through a resistance, it is produced by a specially designed motor-generator set in one unit, called a dynamotor. This machine, together with the necessary controlling and stabilizing apparatus mounted on it is illustrated in Fig. 38. The connections are so arranged in this dynamotor that the current flows from the bond or the rail to the carbon pencil or in the opposite direction to the flow when current is taken directly from the trolley. A great advantage is claimed by the manufacturers in this feature on account of the well-known fact that more heat is developed at the positive than at the negative terminal of an electric arc.

Like all welding operations the character of the work depends largely upon the skill and care of the operator. When properly applied the contact resistance is very low and this combined with the short length of the bonds gives a joint of very low resistance. Moreover, the small amount of metal in the bond reduces the liability of theft. On the other hand, such a short bond is not well adapted to loose joints as the continual vibration incident to traffic will eventually crystallize the laminations, thus leading to the complete failure of the bond.

The dynamotor is so designed that it is adaptable to metallic electrode type of welding and can therefore be used in the shop for general repair work. A stabilizing inductance is furnished for this class of work which is mounted on the side of the machine.

Another type of bond which has been developed by this manufacturer is a cable bond which is applied in a horizontal position under the base of the rail. To apply this bond it is necessary to burn two small notches out of the base of the rail which are filled up with copper during the course of the application. This cable type of bond is advocated for paved-in track where the usual head

bond is subjected to forces which tend to break it from the rail. This type of bond has also found favor in mines where a head bond is likely to be sheared off by dump-car derailments which are said to be frequent occurrences.

(*b*) THE CAST-WELD RAIL JOINT.—While the cast-weld joint has been superseded in most cities by various forms of improved electric or thermit welded joints, it is interesting to note that in a few cities the results obtained were such as to justify their continuous use down to this date, among these cities being Minneapolis, Detroit, and Milwaukee. This joint is also being largely used in Brooklyn. In Milwaukee there are many cast-weld joints which are 20 years old, and which are in such good condition that their location in the track can hardly be distinguished on inspection. A new type of cast-weld joint has recently been developed in Milwaukee which promises to give much better results than the old rectangular form of weld which was formerly used and in which many failures developed. In the new joint by keeping the weld well below the head of the rail and taking precautions to keep the head of the rail cool by means of a water-filled strong back while pouring the weld, the running portion of the rail retains its original properties and does not have so great a tendency to cup under continuous traffic. Fig. 39 shows two of these joints after having been tested to destruction. They were made from 7-inch, 95-pound T rail and the pressure was applied midway between supports, 5 feet apart. The joints failed at 50 tons and 54 tons, respectively. It will be noted that in both cases the failure occurred in the rail and not in the weld. Similar joints failed under a tensile stress of 240 tons with steel bond plugs and 210 tons without steel bond plugs. These tests compare favorably with similar tests on other types of welded joints. The cast weld in this altered form is considered as the standard in Milwaukee, although a considerable percentage of repair joints are now being made by other methods.

(*c*) THERMIT-WELDED RAIL JOINTS.—The present improved form of this joint referred to on pages 20 and 109, but not described, is known as the thermit fully welded rail joint.

In making this weld the rails are spaced three-fourths of an inch apart, in the case of new rail, and a gap of that width is

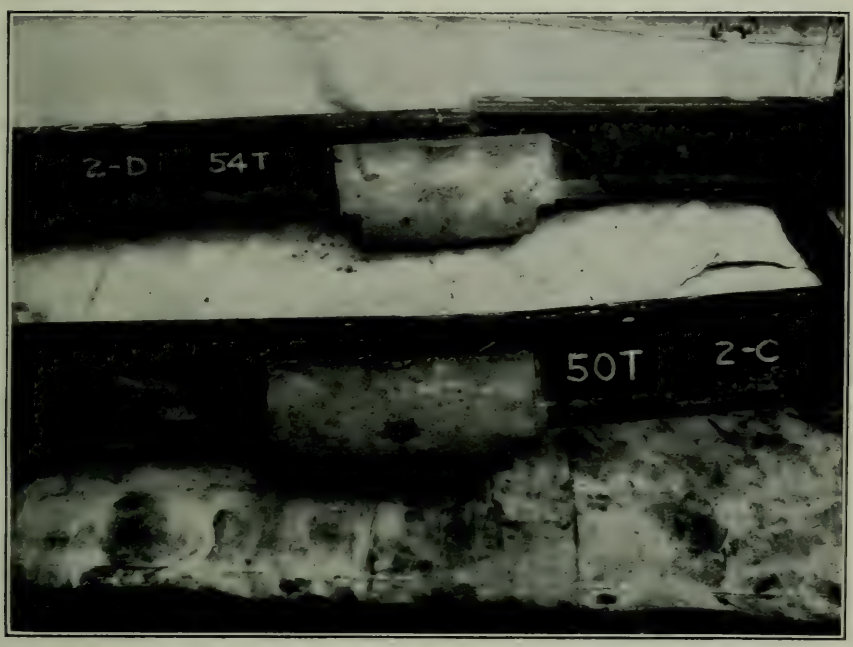

FIG. 39.—*Improved cast weld rail joints tested to destruction*

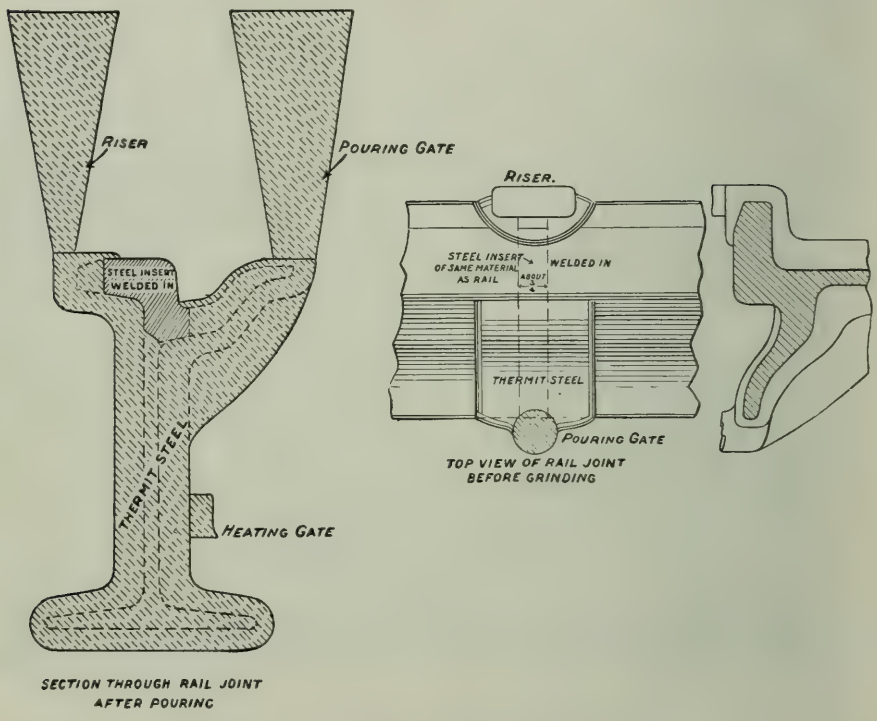

FIG. 40.—*Thermit insert fully welded rail joint*

provided by cutting or sawing in the case of old rail. Into this space and between the heads of the rails only is placed an insert cut from a rolled section of similar analysis to the rail itself. These inserts are provided in a variety of thicknesses to facilitate fitting snugly and the top surface is allowed to project slightly above the surface of the rail head. The accompanying illustration, Fig. 40, shows the position of the insert and how the thermit steel is flowed around the joint to make the weld. The web and base are thoroughly melted and amalgamated with the thermit steel but the entire head of the rail is not. Only the outside of the head and the lip of the rail are melted by the thermit steel. A weld of the entire rail section is obtained, however, when the thermit steel begins to cool and contract. The proximity of this steel to the insert has melted up the lower part of the insert and heated the upper part as well as the abutting heads of the rails to such a high temperature that when contraction sets in, thus drawing the rails together with tremendous force, the effect is to butt weld the insert permanently into place between the rail heads.

The advantage claimed for this method is to be found in the fact that the metal in the head of the rail coming into contact with the car wheels is not melted and its physical properties not changed. As a result, it is said, welds made in this way have shown no tendency to cup after six years of hard service under heavy and frequent traffic. Furthermore, the breakage of welds made in this way has proved to be so small in the six years since the welds have been installed that they can hardly be figured in percentages at all. The manufacturers state that in San Antonio where nearly 10 000 welds have been made since 1913, the number of broken joints has been negligible, and at last reports the number of breaks had averaged less than 1 in 2000 welds. It is claimed that similar reports have been received from other cities where the joint has been installed for several years. Where breaks have occurred they have usually taken place either shortly after welding, indicating something wrong with the procedure, or else they have occurred during the first winter.

An interesting development in the use of thermit for rail welding has been its application to the welding of special work; that is,

making up frogs and crossings by welding together short pieces of rail. The first crossing to be made up in this manner was welded by the Milwaukee Electric Railway & Light Co., Milwaukee, Wis., in 1914, and it is said to have been in good condition in August, 1919. Other companies using the process in the same way are the Indianapolis Traction & Terminal Co., who have been doing it for several years and the Omaha & Council Bluffs Street Railway Co., which has recently taken it up. Fig. 41 shows a piece of thermit special work installed in Indianapolis.

It is said that the thermit-insert weld seems to be the only process which will successfully weld alloy steel rails such as the Mayari rails made by the Bethlehem Steel Co. Other methods have not proved successful in welding these rails but 500 welds were made in Chicago by the thermit-insert process and only 3 joints have broken since. The welds were made in 1915 while the 3 breaks occurred in the winter of 1916. These were rewelded and no further breaks have occurred.

(*d*) THE ELECTRICALLY WELDED JOINT.—The electrically welded joint with spelter head support, shown in Fig. 10, and made by the Lorain Steel Co. has been superseded by a chock head support bar joint shown in Fig. 42. This joint was introduced in 1916. A drop-forged steel chock is welded over the bars at the center to provide a head support for the abutting rails. A weld is made between the back of the rail head and the chock as well as above the bars. Fig. 43 shows an electrically welded chock joint in which the use of the bars has been dispensed with. These joints were first used in Chicago in 1918.

(*e*) ARC-WELDED JOINTS.—A comparatively new type of arc-welded joint is the so-called Gailor joint exploited by the Lincoln Bonding Co. This joint was first put on the market by the Atlantic Welding Corporation and was known as the Atlantic joint. The joint is formed by welding plates, which stand away from the web and fish to head and base, along their top and bottom edges for the full length of the plates. The principal feature of this joint is that the plates support the head on both sides for the full length of the plates. If properly welded, the conductivity of this joint is in excess of that of the rail section. The joint can be made by either using mechanical fishplates on

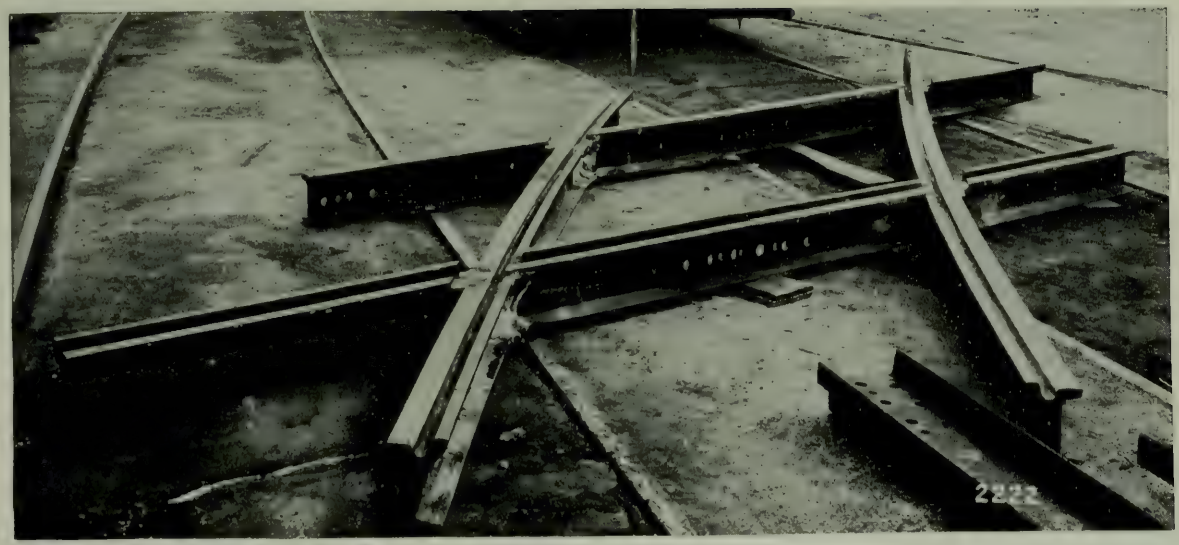

FIG. 41.—*Thermit special work*

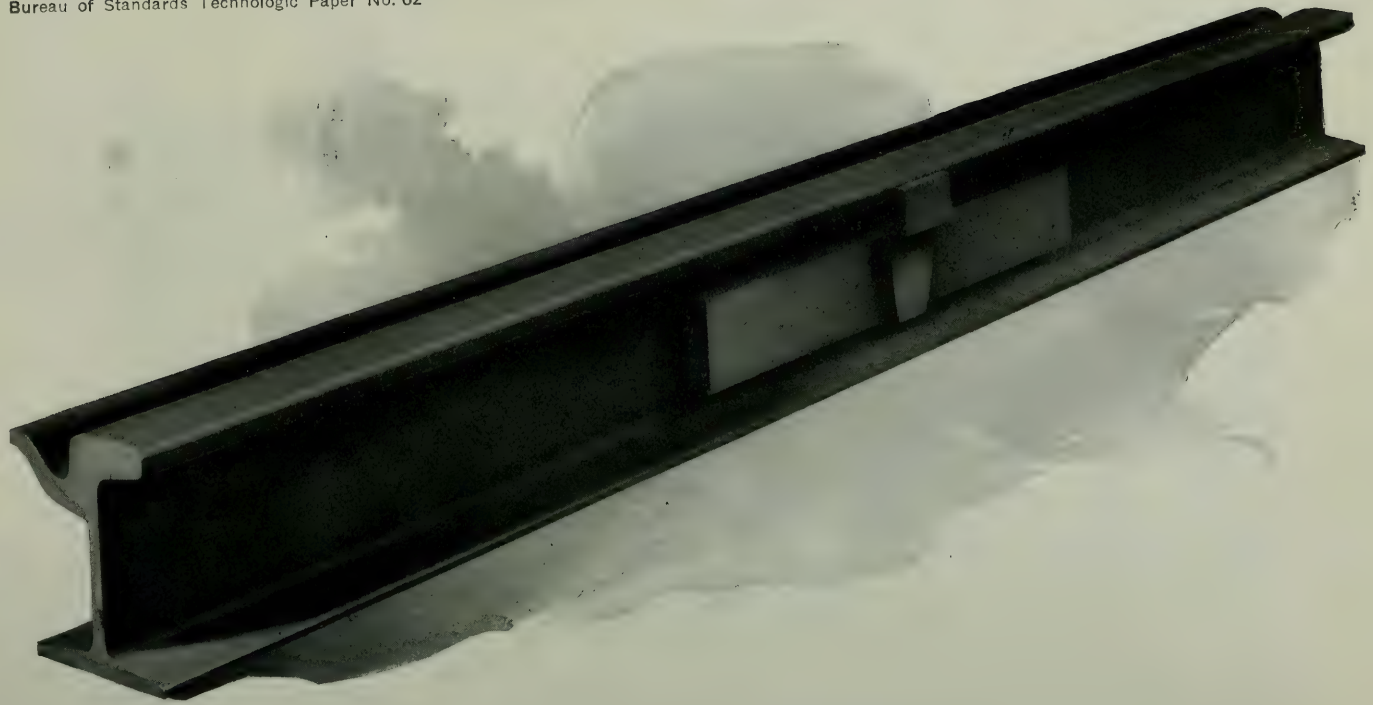

FIG. 42.—*Chock head support bar joint, electrically welded*

FIG. 43.—*Chock joint without bars, electrically welded*

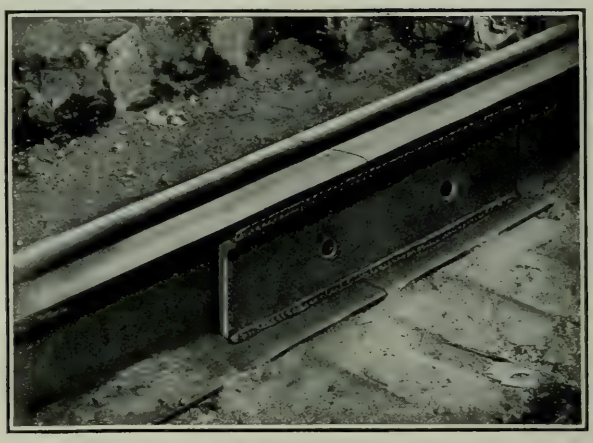

FIG. 44.—*Gailor arc-welded joint*

FIG. 45.—*Dynamotor in use for joint welding in the street*

hand, beveled in accordance with the manufacturer's instructions, or by the railways making plates from bar steel. Special plates may also be obtained from the Rail Joint Co. Fig. 44 shows a welded joint made with flat bar type plates.

A special process of welding is usually employed for welding these joints which makes it possible to conveniently weld the plates to the under side of the rail head. The process is a carbon-arc method in which the welding is performed in the presence of a composition bar high in copper. It is claimed that this bar has a stabilizing effect on the arc and permits of obtaining a good weld with deep penetration at the rate of 6 linear inches per minute. The parts necessary for this welding have been so designed and developed that a minimum amount of equipment is necessary.

The Lincoln Bonding Co. has developed a larger size of their dynamotor weighing about 1300 pounds for the supply of current for this process. This machine is shown in Fig. 45. The accessories and especially the clamps for holding the copper-composition bars have been especially designed to permit welding under traffic and so as not to interfere with other vehicular traffic on the street. It is claimed that with this equipment a crew of 3 men can weld 25 joints per day in new track construction without traffic or 14 joints per day under 3-minute traffic in 7½ hours. The dynamotor of this equipment has also been developed to perform metallic electrode welding for building up cupped rails, for welding rail joints in worn track, and for repairing special work. Like the smaller bonding machine the welding generator is equipped with a stabilizer which is mounted on the side of the machine.

WASHINGTON, October 10, 1919.

DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 63

LEAKAGE OF CURRENTS FROM ELECTRIC RAILWAYS

BY

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Bureau of Standards

ISSUED MARCH 14, 1916

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

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LEAKAGE OF CURRENTS FROM ELECTRIC RAILWAYS

By Burton McCollum and K. H. Logan

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I. INTRODUCTION

The leakage of electric current from street railway tracks used as return conductors is the principal cause of electrolytic corrosion of underground metallic structures. Occasionally electrolysis is due to other causes, such as the leakage of current from power or lighting circuits, but such corrosion is infrequent and usually confined to small areas.

This paper is intended primarily for electric railway engineers, and others familiar with electrolysis problems and a general knowledge of the phenomena and terms of electrolysis is assumed.

It is the purpose of this paper to discuss the factors which influence the escape of current from street railway tracks, indicating the importance of each factor from electrolysis standpoint, and to draw certain conclusions on the electrolysis problem.

A development of the theory of leakage currents is presented first for isolated linear lines and later for any portion of a track

network. The equations developed for the more simple case of an isolated railway line are plotted in the form of curves, which can be more readily interpreted than the equations themselves. In addition to these curves a series of conclusions have been drawn to assist the reader in interpreting the significance of the equations. In another publication [1] of the Bureau of Standards it is shown that one of the most important features of any effective plan of electrolysis mitigation is the reduction of leakage current to the lowest practicable amount. A thorough understanding of the laws governing the leakage of current from railway lines is therefore very important. It is hoped that the theoretical development presented will be of value in assisting the reader to secure a clear idea of the general principles governing leakage of stray currents into the earth.

In developing the theory of leakage currents it is assumed that any polarization effects between tracks and ground are equivalent to a resistance. This assumes that the counter electromotive force of polarization is proportional to the current flowing. In many cases this is approximately true, and since the polarization potentials are in general small compared with the resistance drop between tracks and ground the assumption will introduce no material error. It is further assumed in this theory that substantially all of the resistance between tracks and earth is encountered within a distance from the track which is quite small compared with the length of the railway line under consideration. Numerous experiments have shown that the greater part of the resistance between tracks and remote ground is found within 200 or 300 feet of the track. When we are considering sections of track several thousand feet or more in length, we can, therefore, safely make the above assumption.

II. GENERAL EQUATION FOR LEAKAGE CURRENTS

We have two cases to consider, namely, case I, in which the negative bus is substantially insulated from the earth except through its connection with the railway tracks, and case II, in which the negative bus is grounded at the power house, which in practice would correspond substantially to metallic connection

[1] E. B. Rosa and Burton McCollum, Electrolysis and Its Mitigation, Technologic Paper No. 52, Bureau of Standards.

between pipes and tracks at that point. We shall first develop the general equation which applies to both cases and then determine the constants for the two cases separately.

The following notation is used:

i_o = originating current per unit length of line assumed uniformly distributed.

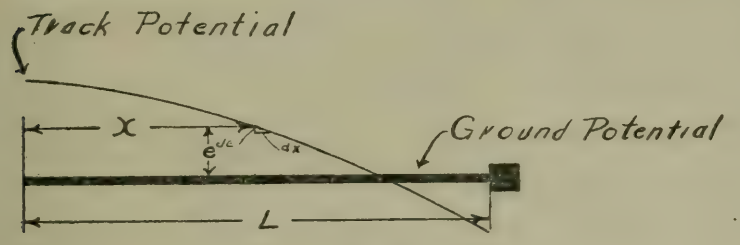

FIG. 1*a*

i = total current in rails at any point distant x from the outer end of the line.

e = potential difference between tracks and ground at any point distant x from the end of the line.

i_1 = total leakage current up to any point.

r = leakage resistance between tracks and remote earth per unit length of line.

δ = resistance of track per unit length of line.

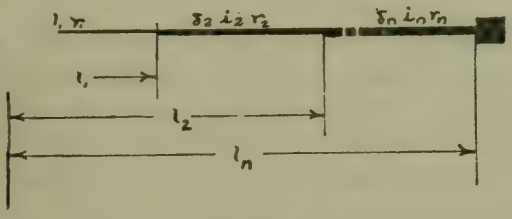

FIG. 1*b*

x = distance from outer end of line of any point under consideration.

L = total length of line.

Referring to Fig. 1*a*, the increase in potential difference de in a length dx at any point x on the line will be

$$de = -i\delta dx$$

$$\therefore \frac{de}{dx} = -i\delta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The increase in current in the element of length dx is equal to the originating current in that length less the leakage current. The originating current is equal to $i_o dx$, and the leakage current is equal to $\frac{e}{r}dx$. Hence we have

$$di = i_o dx - \frac{e}{r}dx$$

$$\therefore \frac{di}{dx} = i_0 - \frac{e}{r}$$

$$\frac{d^2i}{dx^2} = -\frac{1}{r}\frac{de}{dx}$$

$$\therefore \frac{de}{dx} = -r\frac{d^2i}{dx^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

From (1) and (2)

$$r\frac{d^2i}{dx^2} - i\delta = 0$$

$$\therefore \frac{d^2i}{dx^2} - i\frac{\delta}{r} = 0$$

This equation readily integrates into

$$i = Ae^{\sqrt{\frac{\delta}{r}}(x)} + Be^{-\sqrt{\frac{\delta}{r}}(x)} \quad \ldots\ldots\ldots\ldots (3)$$

Equation (3) is the general equation giving the current strength at any point in the tracks distant x from the end of the railway line, and applies to both case I and case II, the difference in the two cases being only in the constants of integration A and B.

Equation (3) shows that for a track of given length and originating current per unit length, the total current in the rails at any point depends upon three factors, namely, the distance of the point from the outer end of the track, the resistance of the track per unit of length, and the leakage resistance per unit length between the tracks and earth at a considerable distance from the rail.

The resistance of the rail varies with its temperature and depends also upon the size of the rail, the material from which it is rolled, and the treatment during manufacture. For rough calcu-

lations we have assumed a resistance of 0.01 ohm per 1000 feet of 100-pound rail and taken the resistance of other rails as inversely proportional to their weights. This figure represents an average of a large number of values of resistances of rails of various sizes and from several makers.

The resistance of the roadbed varies between wide limits, and experiments are now in progress for the study of roadbed characteristics. These experiments so far indicate that the roadbed resistance varies with the type of construction, the weather, and the kind of soil upon which it is laid.

The leakage resistance of single track ranges between about 0.2 and 12 ohms per 1000 feet for constructions usually employed. In special cases, where the rails are laid in moist earth of high conductivity or crushed rock in a very dry region, the resistance may not fall within these limits. For double track the resistance may theoretically vary from 50 to 100 per cent of this, according to whether most of the resistance is near the rails or remote therefrom, and in most practical cases it will vary from 60 to 80 per cent of that for single track of similar construction.

Since the leakage current up to any point is equal to $i_o x - i$, the effect of track resistance on leakage current is seen from equation (3) to be exactly the inverse of the leakage resistance; hence an increase in leakage resistance in any given ratio reduces the leakage currents in the same degree as increasing the conductance of the tracks in the same ratio. This emphasizes the importance of so constructing the roadbed as to give the highest practicable leakage resistance. Since in the equations which follow the factor $\sqrt{\frac{\delta}{r}}$ occurs repeatedly, the equations will be simplified in form by letting $\sqrt{\frac{\delta}{r}} = a$. Making this substitution in equation (3) we get the simplified form:

$$i = Ae^{ax} + Be^{-ax}. \quad \ldots\ldots\ldots\ldots \quad (3a)$$

It is apparent that the form of the curves is determined not by the numerical values of δ and r, but by the ratio of these factors. In order to facilitate the interpretation of the equations there is given in each case certain combinations of δ and r which might

be encountered in practice, and which would give the values of a used.

The value of a will vary between wide limits. For example, if the track resistance be very low, such as when well-bonded 125-pound rails are used, the value of δ for a single track would be 0.004 ohm per 1000 feet. If, also, the leakage resistance has a high value, such as 12 ohms per 1000 feet, the value of a will be 0.018. On the other hand, if the track resistance be high, such, for example, 0.04 ohm per 1000 feet, due to very bad bonding, and if, at the same time, the leakage resistance be as low as 0.2 ohm per 1000 feet, the value of a would be 0.45. Under most practical conditions the value of a may be taken to range between 0.025 and 0.25, or in the ratio of about 10 to 1. The quantity a is called the "leakage factor" of the railway line. It will be shown later in the discussion of the theory of leakage currents that it is very important that the value of a be kept as low as possible. This can be done either by maintaining good track bonding and by the use of heavy rails, or by so constructing the roadbed that the leakage resistance will be high.

III. LEAKAGE CURRENTS FOR UNIFORM LINE

We shall now proceed to examine in detail the application of equation 3a to the two cases encountered in practice, first with the negative bus not grounded, and next with the bus grounded.

1. (CASE I) BUS NOT GROUNDED

At the outer end of the line $x=0$, and the current $i=0$. Since the bus is not grounded, all of the current which leaks off the track must return to the track. Hence, when $x=L$, the length of the line, the current in the tracks must be i_0L. Imposing these conditions on equation 3a and solving for the constants A and B we get the following:

When $x=0$ $A+B=0$, or $A=-B$.

When $x=L$, $Ae^{aL}+Be^{-aL}=i_0L$

$$i_0L=(e^{aL}-e^{-aL})A$$

$$\therefore A=\frac{i_0L}{e^{aL}-e^{-aL}}$$

From (3*a*) and the above relation $A = -B$ we have:

$$i = A[e^{ax} - e^{-ax}] = \frac{i_o L}{e^{aL} - e^{-aL}}[e^{ax} - e^{-ax}] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

$$\therefore i = \frac{i_o L}{\sinh\ (aL)} \cdot \sinh\ (ax) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

The total current originating in the tracks between the end of

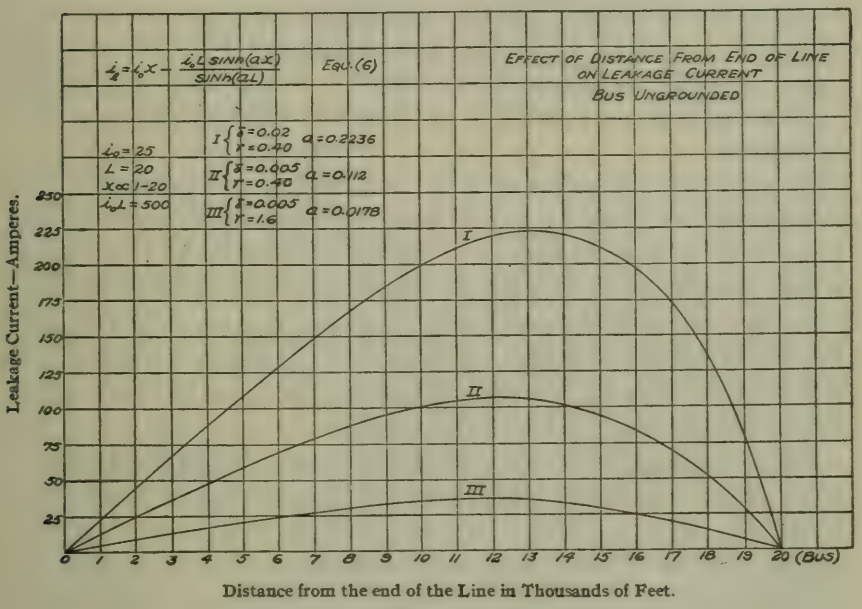
$i_x = i_o x - \frac{i_o L \sinh(ax)}{\sinh(aL)}$ Equ. (6)
Effect of Distance From End of Line on Leakage Current
Bus Ungrounded
$i_o = 25$
$L = 20$
x as 1-20
$i_o L = 500$
I $\begin{cases} s = 0.02 \\ r = 0.40 \end{cases}$ $a = 0.2236$
II $\begin{cases} s = 0.005 \\ r = 0.40 \end{cases}$ $a = 0.112$
III $\begin{cases} s = 0.005 \\ r = 1.6 \end{cases}$ $a = 0.0178$
Leakage Current—Amperes.
250
225
200
175
150
125
100
75
50
25
I
II
III
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 (Bus)
Distance from the end of the Line in Thousands of Feet.

FIG. 2

the line and any point x is $i_o x$. Hence, the total leakage current up to any point x is

$$i_1 = i_o x - i$$

$$\therefore i_1 = i_o x - \frac{i_o L}{\sinh\ (aL)} \cdot \sinh\ (ax) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

The curves in Fig. 2 plotted from equation (6) show the magnitude of the total leakage current at each point along a 20 000-foot single track for three conditions of rail and leakage resistance, the originating current being assumed to be 25 amperes per 1000 feet of track.

In Fig. 2 three curves are shown. Curve *I* shows the leakage current at various points on a line for which the track resistance δ is 0.02 ohm per 1000 feet due to bad bonding, and the leakage resistance r is 0.4 ohm per 1000 feet, a value not unusually low. This gives a value of a equal to 0.2236. The maximum leakage current in this case is seen to occur at about 13 000 feet from the end of the line and amounts to about 220 amperes. The current originating in the tracks being 25 amperes per 1000 feet the total originating current is $25 \times 20 = 500$ amperes. Of this, 220 amperes, or about 44 per cent, has leaked to earth. This represents a very bad leakage condition, but one not infrequently met with in practice.

In curve *II* the value of δ is 0.005 ohm per 1000 feet, which corresponds to a well-bonded track of 100-pound rails, and the same value of r as in curve *I*. This gives a value of 0.112 for a, which represents a fair average value of the leakage factor. The difference between curves *I* and *II* shows the effect of reducing the track resistance from 0.02 to 0.005 ohm per 1000 feet, and it will be seen that the maximum leakage has been reduced to less than one-half of the value shown by curve *I*.

Curve *III* represents a very good condition regarding leakage, the track resistance being fairly low and the leakage resistance 1.6 ohms per 1000 feet, which is a moderately high value, although one which may often be exceeded in practice. δ is 0.005 ohm per 1000 feet, giving a value of $a = 0.0178$. Comparison of curves *II* and *III*, which are for the same track resistance, shows the effect on the leakage current of increasing the leakage resistance.

The leakage current decreases with decreasing values of a. The point at which the leakage current is a maximum is, of course, the neutral area in the electrolysis region at which point the earth and the tracks are at the same potential. This point is seen to shift toward the negative bus as the maximum leakage increases. This change in the size of the positive and negative areas will be shown more clearly by a later curve when its significance will be discussed. For high values of the leakage factor a the leakage current will be seen to increase more rapidly than the value of a,

which emphasizes the importance of maintaining the value of a as low as practicable.

For maximum leakage

$$\frac{di_1}{dx}=0$$

From (6)

$$\frac{di_1}{dx}=i_o-\frac{i_oLa}{\sinh\,(aL)}\cdot\cosh\,(ax)=0$$

$$\therefore\ \cosh\,(ax)=\frac{\sinh\,(aL)}{(aL)} \qquad (7)$$

$$\therefore\ x=\frac{1}{a}\cosh^{-1}\left[\frac{\sinh\,(aL)}{(aL)}\right] \qquad (8)$$

$=$ value of x for neutral zone.

Substituting from (8) and (6) we get the value of maximum leakage.

$$\text{Max } i_1=i_o\frac{1}{a}\cosh^{-1}\left[\frac{\sinh\,(aL)}{aL}\right]-\frac{i_oL}{\sinh\,(aL)}\sqrt{\frac{\sinh^2\,(aL)}{a^2L^2}-1}$$

$$\frac{i_1\,max}{i_oL}=\frac{1}{aL}\left[\cosh^{-1}\,u-\frac{1}{u}\sqrt{u^2-1}\right] \qquad (9)$$

$$\text{where } u=\frac{\sinh\,(aL)}{aL}$$

Equation 9 is plotted in Fig. 3 with length of line, L, as abscissae for $i_o=40$ amperes per 1000 feet, $\delta=0.005$, and $r=0.4$, which corresponds to a fair average condition.

The curves indicate that the leakage current increases much faster than the length of the line, especially for lines of moderate length, and shows the importance from an electrolysis standpoint of reducing the feeding distance as much as possible.

Fig. 4 is the same as the lower part of Fig. 3 plotted on a larger scale, together with the dotted curve of a parabola. It indicates that for feeding distances up to about 10 000 feet the maximum leakage current increases approximately as the square of the feeding distance.

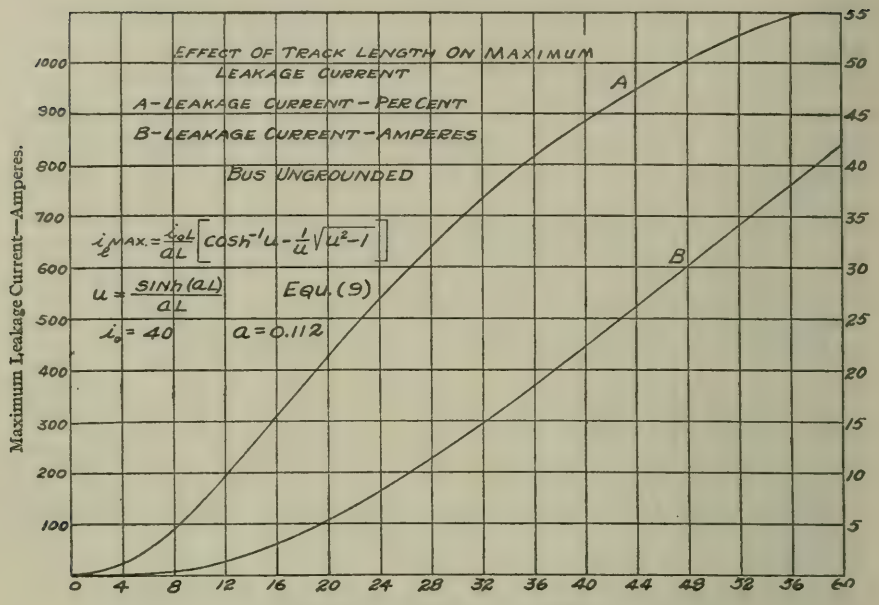
EFFECT OF TRACK LENGTH ON MAXIMUM LEAKAGE CURRENT
A-LEAKAGE CURRENT-PER CENT
B-LEAKAGE CURRENT-AMPERES
BUS UNGROUNDED
$i_{g\,MAX.} = \frac{i_o L}{aL}\left[\cosh^{-1} u - \frac{1}{u}\sqrt{u^2-1}\right]$
$u = \frac{\sinh(aL)}{aL}$ EQU. (9)
$i_o = 40$ $a = 0.112$
A
B
Maximum Leakage Current—Amperes.
Length of Line in Thousands of Feet.

FIG. 3

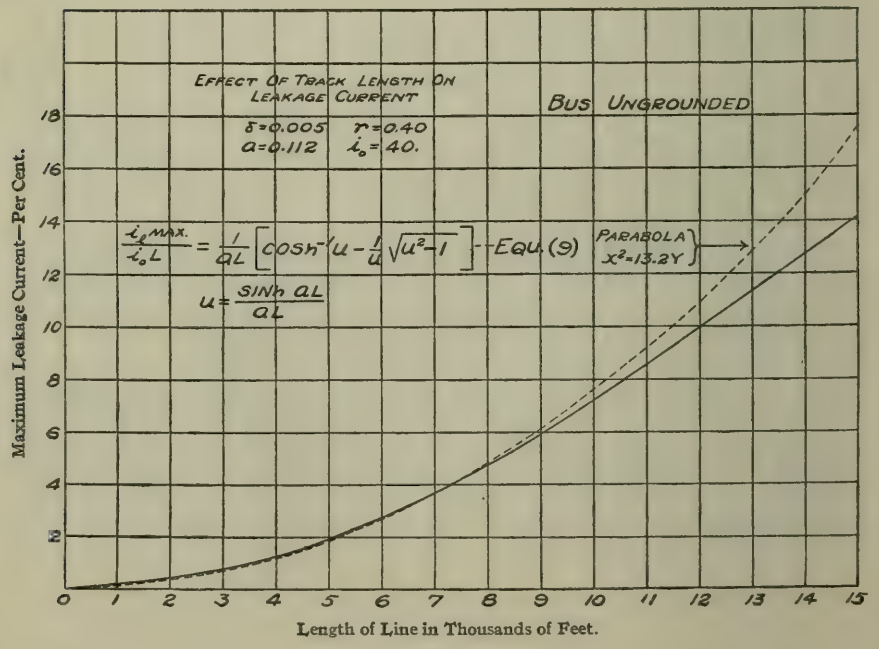
EFFECT OF TRACK LENGTH ON LEAKAGE CURRENT
BUS UNGROUNDED
$\delta = 0.005$ $r = 0.40$
$a = 0.112$ $i_o = 40.$
$\frac{i_{g\,MAX.}}{i_o L} = \frac{1}{aL}\left[\cosh^{-1} u - \frac{1}{u}\sqrt{u^2-1}\right]$ EQU. (9)
$u = \frac{\sinh aL}{aL}$
PARABOLA $x^2 = 13.2Y$
Maximum Leakage Current—Per Cent.
Length of Line in Thousands of Feet.

FIG. 4

For long feeding distances the rate of change of maximum leakage current is much less than for short feeding distances.

Fig. 5 represents equation 9 with the rail resistance as the independent variable. The maximum leakage current increases much less rapidly than the track resistance, except where the track resistance is very low.

In Fig. 6, equation 9, is plotted with the leakage resistance as the independent variable. If the leakage resistance is small,

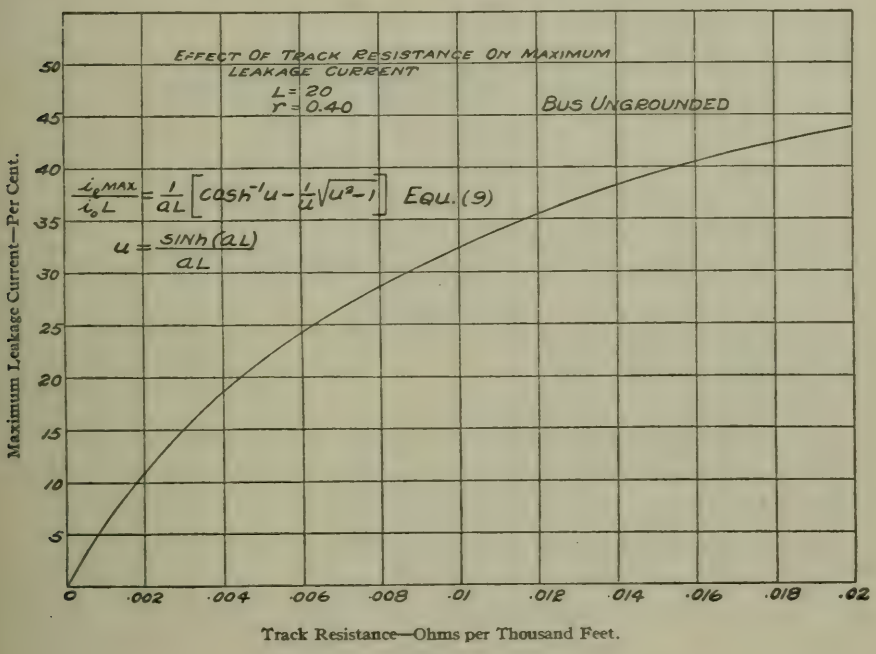

FIG. 5

such as that corresponding to an average concrete roadbed or track embedded in damp soil, the leakage current decreases very rapidly with increased leakage resistance.

2. (CASE II) BUS GROUNDED

This differs from case I only in the terminal conditions. From case I.

$$i = Ae^{ax} + Be^{-ax} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

when $x = 0$. $i = 0$. $\therefore A = -B$ $\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$ (11)

Where $x = L$—that is, at the power house—we assume that the tracks are perfectly grounded so that the potential difference

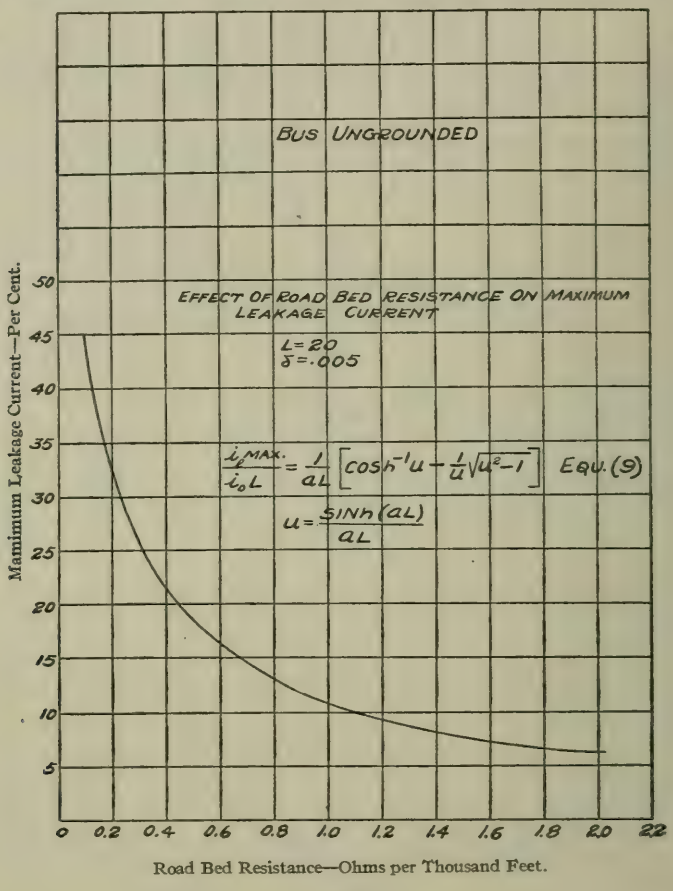

FIG. 6

between tracks and earth is zero, and therefore there is no leakage at this point.

Hence, for $x = L$ we have $\frac{di}{dx} = i_o$

Differentiating 10 with respect to x

$$\frac{di}{dx} = Aa.e^{ax} - Ba.e^{-ax}$$

$$\therefore Aa.e^{al} - Ba.e^{-al} = i_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11a)$$

From (11) and (11*a*).

$$A = \frac{i_o}{a(e^{aL} + e^{-aL})} = \frac{i_o}{2a \cosh (aL)}$$

$$\therefore\ i = \frac{i_o}{2a \cosh (aL)} (e^{ax} - e^{-ax}) = \frac{i_o \sinh (ax)}{a \cosh (aL)} \quad \ldots\ldots\ldots\ldots\ (12)$$

$$i_1 = i_o x - i = i_o x - \frac{i_o \sinh (ax)}{a \cosh (aL)} \quad \ldots\ldots\ldots\ldots\ (13)$$

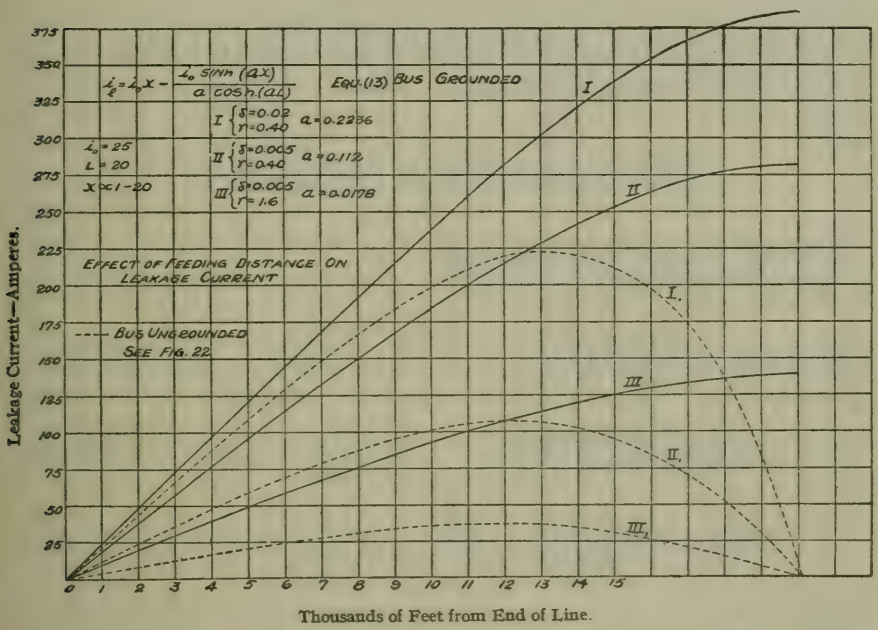

FIG. 7

Fig. 7 represents equation 13 for conditions similar to those for Fig. 2 except that the solid lines show the conditions for bus grounded. The ground connection is assumed to have negligible resistance. Fig. 7 shows that grounding the bus, as by connecting it to a buried pipe system, greatly increases the leakage current. In order to facilitate comparison the curves of Fig. 2 for the bus ungrounded are reproduced in the dotted curves of Fig. 7. The leakage current continues to increase as the power house is approached, but at a diminishing rate. It will be seen that

for moderate and good leakage conditions (curves *II* and *III*) increase in leakage resistance has a greater effect in reducing leakage currents if the bus is grounded than when it is ungrounded.

When conditions are such as to give rise to only moderate leakage currents, the maximum leakage will be more than doubled by grounding the negative bus. This is shown by curves *III* and III_1. When leakage conditions are bad the ratio of increase in leakage current due to grounding is less, but the increase is still quite marked as shown by curves *I* and I_1. Since the leakage current may not be confined to the underground structure to which the bus is connected the curves emphasize the importance of insulating the negative bus.

When

$$\frac{di_1}{dx}=0 \quad \cosh(ax)=\cosh(aL) \text{ or } x=L$$

$\therefore$ Leakage is maximum for $x=L$

$\therefore$ Maximum leakage =

$$\text{Max. } i_1=i_0L-\frac{i_0 \sinh(aL)}{a\cosh(aL)} \qquad (14)$$

$$=i_0L\left(1-\frac{\tanh(aL)}{aL}\right) \qquad (15)$$

$$=i_0L\left(1-\frac{\tanh(v)}{v}\right) \qquad (16)$$

where $v=aL$.

Fig. 8 shows the relation between the length of the line and the leakage current for a rather heavily loaded line with good rails and roadbed corresponding to down-town conditions in a city of medium size. It will be seen that with the bus grounded the maximum leakage increases more rapidly than the feeding distance. This is particularly true for feeding distances up to 15 000 or 16 000 feet. It is evident from Fig. 8 that for very long feeding distances, such as are frequently encountered on interurban lines, practically all of the current may return by way of the earth.

IV. POTENTIAL GRADIENTS

From the equations for current in cases I and II we can determine the potential gradients on the tracks, the over-all potential drops and the potential difference between tracks and ground.

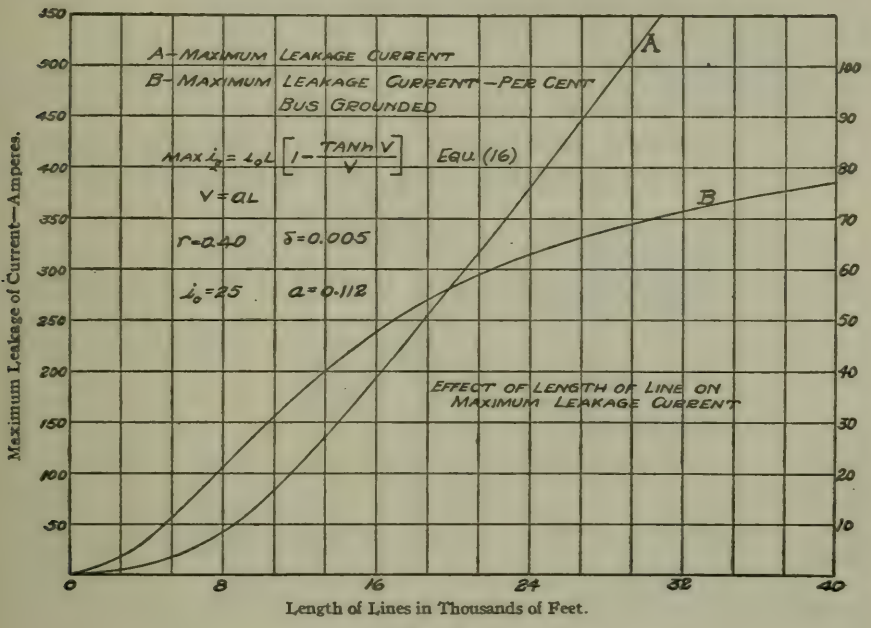

FIG. 8.

1. (CASE I) BUS NOT GROUNDED

From equation 5 we have

$$i = \frac{i_0 L \sinh (ax)}{\sinh (aL)}$$

The potential gradient in the track is $\frac{de}{dx} = i\delta = E_1$

$$\therefore E_1 = \frac{i_0 \delta \, L \sinh (ax)}{\sinh (aL)} \qquad (17)$$

If there were no leakage the gradient would obviously be

$$E_1^1 = i_0 \delta x \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (18)$$

2. (CASE II) BUS GROUNDED

From equation 12 after multiplying by δ we have

$$E_2 = \frac{i_0 \delta \sinh (ax)}{a \cosh (aL)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (19)$$

Fig. 9 illustrates the potential gradients indicated by equations 17 and 19 under the same track and load conditions with the

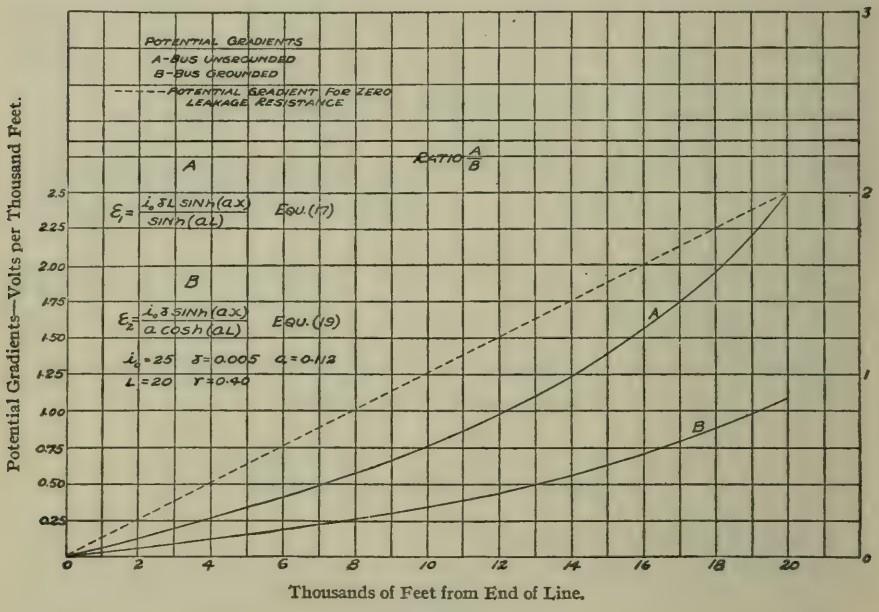

FIG. 9

bus ungrounded and grounded. The broken line indicates the gradient given by equation 18 when the entire current is confined to the rails.

It will be seen that potential gradients in the tracks may be materially reduced due to leakage currents, and this reduction is more marked if the bus is grounded.

Dividing equation 19 by 17 we get as the ratio of the gradients at any point under the two cases.

$$\frac{E_2}{E_1}=\frac{\tanh\ (aL)}{aL} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (20)$$

The ratio of the gradients in the two cases is thus independent of x, and for large values of L the ratio becomes practically inversely as L. Thus, when the negative bus is ungrounded the potential gradients are greater than if the bus is grounded and the difference is very marked where the feeding distances are long.

For very long lines the ratio varies practically inversely as the length of the line.

V. OVER-ALL POTENTIALS.

1. (CASE I) BUS NOT GROUNDED

The over-all potential drop is $E=\int_0^L e dx$. Hence, from (17) we have:

$$E_1=\frac{i_0\delta L}{\sinh\ (aL)}\int_0^L \sinh\ ax dx$$

$$=\frac{i_0\delta L}{a\ \sinh\ (aL)}\Big[\cosh\ (ax)\Big]_0^L$$

$$\therefore E_1=\frac{i_0\delta L}{a\ \sinh\ (aL)}\Big[\cosh\,(aL)-1\Big] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (21)$$

If there were no leakage, the over-all potential drop would be:

$$\therefore E_1^1=\int_0^L i\delta dx=i_0\delta\int_0^L x dx=\frac{i_0\delta L^2}{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (22)$$

This value is also derivable directly from equation 21 by making $r=\infty$ whence $a=_0$.

2. (CASE II) BUS GROUNDED

From equation 19 we have:

$$E_2=\int_0^L E_2 dx=\frac{i_0\delta}{a\ \cosh\,(aL)}\int_0^L \sinh\ a\ x dx$$

$$\therefore E_2=\frac{i_0\delta}{a^2\ \cosh(aL)}\Big[\cosh\ (ax)\Big]_{x=0}^{x=L}$$

$$\therefore E_2=\frac{i_0\delta}{\cosh\ (aL)}\Big[\cosh\,(aL)-1\Big] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (23)$$

Dividing equation 23 by 22 we get as the ratio of the over-all potentials in the two cases:

$$\frac{E_2}{E_1} = \frac{\tanh(aL)}{aL} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (24)$$

This last result is, of course, deducible directly from equation 20, since if the ratio of the gradients at any point is constant through-

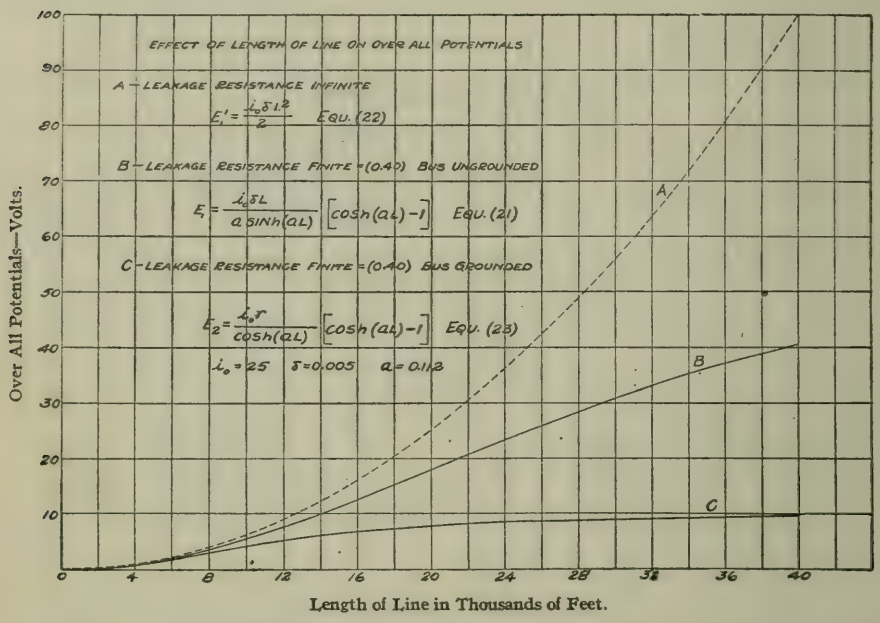

FIG. 10

out the entire line the ratio of the over-all potentials must be equal to this constant ratio.

The curves of Fig. 10 are plotted from equations 21, 22, and 23 and indicate the effect of the feeding distances on over-all potentials. The reduction of over-all potentials due to leakage is relatively much greater in long lines than in short lines and greater with grounded than with ungrounded bus. For very long lines and the moderate leakage and track resistance assumed in plotting these curves the over-all potentials are reduced in case of the ungrounded bus to about 40 per cent and in the case of the

grounded bus to about 10 per cent of the values they would have if there were no leakage.

If there be no leakage, the over-all potential drop is proportional to the first power of the track resistance and to the square of the feeding distance.

If there is leakage and the bus is ungrounded, then, as either the track resistance or the feeding distance increases indefinitely, the over-all potential tends to become proportional to the square root of the track resistance and to the first power of the feeding distance.

As the track resistance or the feeding distance increases indefinitely the over-all potential in the case of the grounded bus tends to become independent of both the track resistance and the feeding distance.

VI. POTENTIAL DIFFERENCE BETWEEN TRACKS AND GROUND

1. (CASE I) BUS NOT GROUNDED

The intensity of current leakage at any point is equal to $\frac{di}{dx}$l and the potential difference between tracks and ground is $r\frac{di}{dx}$l, r being as before the leakage resistance per unit length.

From equation 6 we have

$$\frac{di_1}{dx} = i_o - \frac{i_o al \cosh (ax)}{\sinh (al)}$$

$$\frac{di_1}{dx} = i_o\left[1 - \frac{al \cosh (ax)}{\sinh (al)}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (25)$$

The potential difference between tracks and ground is therefore

$$\Pi_1 = r\frac{di_1}{dx} = i_o r\left[1 - \frac{al \cosh (ax)}{\sinh (al)}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (26)$$

The effects of leakage resistance and rail resistance on potential differences between tracks and the earth are shown by Figs. 11 and 12. If the bus is ungrounded, the intensity of the leakage current at the outer end of the line is less than at the power house

end (current returning to the tracks may be regarded as negative leakage current), and the difference is greater the lower the leakage resistance and the greater the rail resistance. It can be shown that the difference also increases with the length of track. Hence operating with the trolley negative would, in general, tend to reduce the rapidity with which trouble would become acute. The corrosion would, however, be distributed over a larger territory and its total amount would be substantially unchanged.

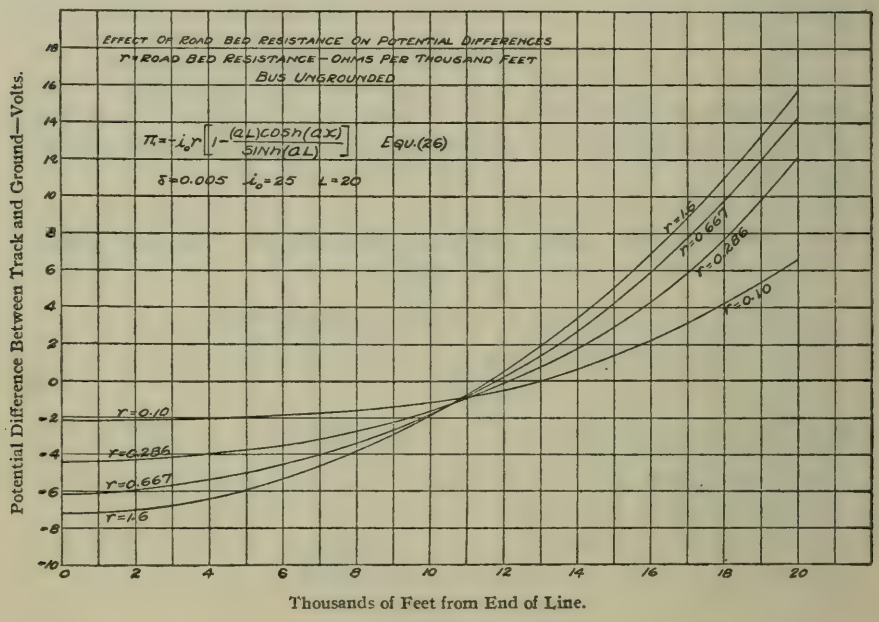

FIG. 11

Although high leakage resistance lowers the leakage current and hence the danger from electrolysis, as is shown by Fig. 6, it also increases the potential difference between the tracks and the earth, and increases the size of the positive area as is shown by Fig. 11. High potential differences are not in themselves, therefore, a definite indication of leakage current, and they may even indicate good, rather than bad, electrolysis conditions, depending upon whether the high voltage is due to high roadbed resistance, high track resistance, or overloading of rails. This is shown by Fig. 12.

As the track resistance or the feeding distance increases indefinitely, the potential difference between the tracks and the ground at the power house becomes indefinitely large and the area of the positive zone becomes indefinitely small. This is shown in Fig. 12 and by equation 26 and less clearly in Fig. 2 where the point of maximum leakage—that is, the neutral zone—was seen to shift toward the power house with increasing values of a. Thus, with

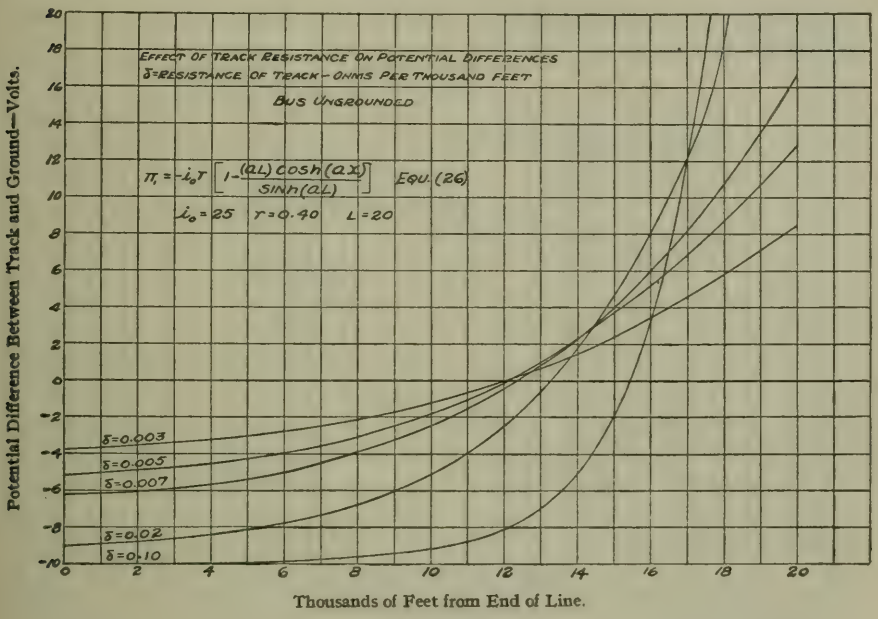

FIG. 12

high track resistance or long feeding distances there will be very severe trouble in a relatively small area.

Long feeding distances, high track resistance, and low leakage resistance all tend to reduce the size of the positive area, although tending to increase the total amount of leakage current, and hence they greatly increase the severity of the electrolysis trouble near the power house. A relatively small positive area, therefore, is an indication of bad electrolysis conditions generally. The length of the positive zone varies from a maximum of 42 per cent of the feeding distance under ideal electrolysis conditions (zero

leakage) to an indefinitely small value where electrolysis conditions are particularly bad. This is indicated by Fig. 12. At the end of the line, where $x=0$, we get the maximum value of potential difference which exists beyond the neutral point. Its value is

$$\Pi_1' = i_0 r \left[1 - \frac{aL}{\sinh (aL)} \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (27)$$

If either δ or L is indefinitely increased, Π_1' approaches as a limit the value $i_0 r$.

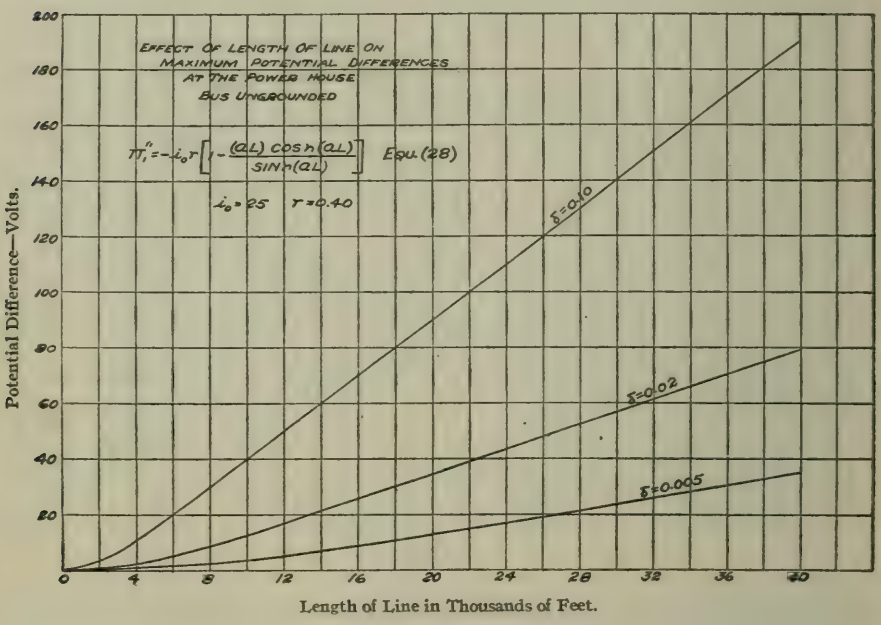

FIG. 13

At the power house end of the line, where $x=L$, the value of the potential difference is

$$\Pi_1'' = i_0 r \left[1 - \frac{aL \cosh (aL)}{\sinh (aL)} \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (28)$$

Fig. 13 shows the variation in the maximum potential difference between the track and the ground for various feeding distances when the bus is not grounded. Three curves are given showing the effect of varying the track resistance.

2. (CASE II) BUS GROUNDED

From equation (13) we have

$$\frac{di_1}{dx} = i_o\left[1 - \frac{\cosh\ (ax)}{\cosh\ (aL)}\right]$$

$$\therefore \Pi_2 = i_o r\left[1 - \frac{\cosh\ (ax)}{\cosh\ (aL)}\right] \qquad (29)$$

With the bus grounded the potential difference at the power house is of course zero, and the increase in leakage current shown

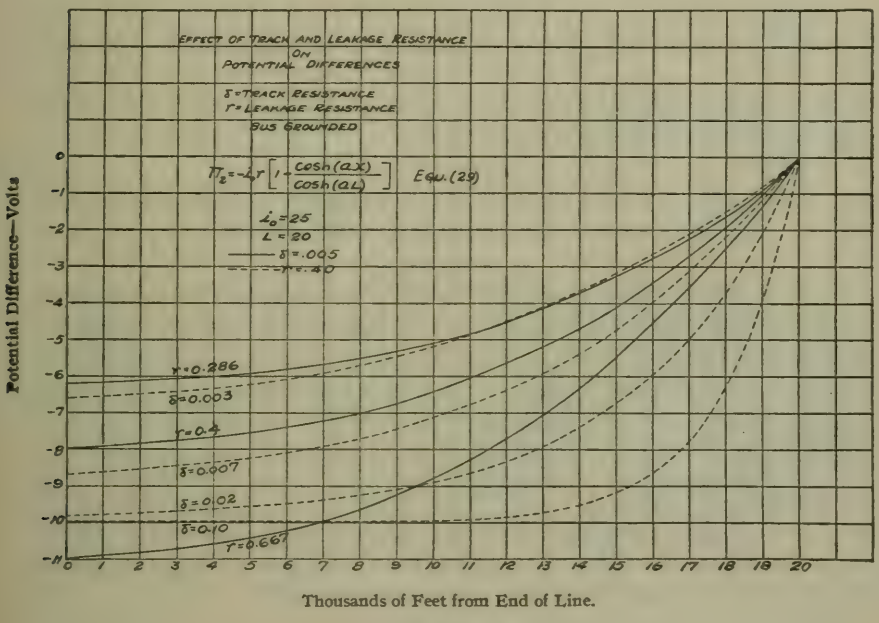

FIG. 14

in Fig. 7 indicates that the change in potential difference will also be most rapid in the region of the power house.

Increasing either the roadbed or the track resistance increases the potential difference at the end of the line, as is indicated by Fig. 14. In this figure there are shown two sets of curves, one set in solid lines plotted for a constant value of track resistance of 0.005 ohm per 1000 feet and varying values of leakage resist-

ance ranging from 0.286 to 0.667 ohm. The dotted curves show the effect of varying the track resistance from 0.003 to 0.10 ohm per 1000 feet with a constant leakage resistance of 0.4 ohm per 1000 feet. It will be observed that in this case leakage resistance is much more influential with respect to potential difference on the outer portions of the line than track resistance, a change in the leakage resistance in the ratio of 2.3 to 1 giving results of approximately the same order of magnitude as a change of 30 to 1 in the track resistance.

At end of line where $x=0$, we have:

$$\Pi_2^1 = i_o r\left[1 - \frac{1}{\cosh\ (aL)}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (30)$$

Here also for large values of δ and L the potential difference approaches the limiting value of $i_o r$.

VII. GENERAL EQUATIONS FOR LEAKAGE FROM ANY SECTION OF A TRACK NETWORK

In this case both leakage resistance and track resistance may be discontinuous functions of the distance along tracks, and in general the bus will not be grounded (Fig. 15). The differential equation for this case is derived in the same way as in case I and has the same form, the only difference in the solution being that in the present case the limits of the integration, instead of being throughout the line, are between the ends of the sections, the constants of the equation changing at each transition point. The equation for i, the current at any point in the n^{th} section from the outer end of line is

$$i = Ae^{a_n x} + Be^{-a_n x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (31)$$

where x is the distance from the end of the line to any point in the n^{th} section under consideration. Applying this equation to the n^{th} section where the limits of integration are L_{n-1} and L_n we have as the limiting conditions

$$x = l_{n-1} \qquad i = I_{n-1}$$
$$x = l_n \qquad i = I_n$$

Substituting these limits in equation 31 and solving for A and B, we get

$$A = \frac{I_{n-1}\, e^{a_n}\, (l_{n-1}-l_n) - I_n}{e^{a_n}\, (^2\, l_{n-1}-l_n) - e^{(a_n)}\, (l_n)}$$

$$B = \frac{I_n\, e^{a} l_n\, ^{(n-1)} - I_{n-1}\, e^{(a_n)}\, (l_n)}{e^{\,a_n}\, (l_{n-1}-l_n) - e^{-a_n}\, (l_{n-1}-l_n)}$$

Substituting these values of A and B in equation 31, we get as the equation for the current in the tracks at any point within the n^{th} section.

$$i = \frac{(I_n\, e^{-a_n}(l_{n-1}) - I_{n-1}\, e^{-a_n} l_n)\, e^{a_n x} - (I_n\, e^{a_n}\, (l_{n-1}) - I_{n-1}\, e^{a_n} l_n)\, e^{-a_n x}}{2 \sinh\, (a_n)\, (l_n - l_{n-1})} \quad (32)$$

If there were no leakage within the n^{th} section, the current at any point x would be $I_{n-1}+i_n\,(x-l_{n-1})$. Hence the leakage current within the section up to any point x is

$$i_1 = I_{n-1} + i_n\, (x-l_{n-1}) - i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (33)$$

The value of i in this equation is given by equation 32.

Equation 33 corresponds to equation 6 and furnishes a similar basis for the development of more general equations for leakage currents, gradients, potential differences, and over-all potentials when the track under consideration is made up of sections differing in weight of rail or in the construction of the roadbed. The equations already developed will serve, however, to show the general effect of variation in rail and leakage resistance.

VIII. INTERPRETATION OF EQUATIONS

An examination of the foregoing equations permits the following deductions in regard to the effect of track resistance, leakage resistance, and feeding distances, or on the current and voltage conditions in a uniformly loaded railway line. Most of these deductions have previously been set forth more in detail in connection with the discussion of the equations but are grouped and restated here for convenience.

1. The voltage and current conditions in the return circuit are characterized by three constants, namely, the resistance of the

track per unit length, the leakage resistance between track and ground per unit length, and the feeding distance (equation 4 and following).

2. The effect of track resistance on leakage currents is exactly the inverse of leakage resistance; hence an increase in leakage resistance in any given ratio reduces leakage currents in the same degree as increasing the conductance of the tracks in the same ratio. This emphasizes the importance from an electrolysis standpoint of so constructing the roadbed as to give the highest practicable leakage resistance (equation 6 and Fig. 2).

3. The leakage current from any given line increases much faster than the length of the line (equation 6 and Fig. 3). This shows the importance of reducing feeding distances as much as practicable.

4. Where the bus is not grounded there will be distinct positive and negative areas and the relative extent of the positive and negative areas is not a constant but varies with the length of the line, the track resistance, and the leakage resistance.

5. For short track lengths the percentage of the total current which leaks from the tracks increases practically as the square of the feeding distance (equation 9 and Fig. 4).

6. For long feeding distances the rate of change of leakage current with distance is much less than for short feeding distances (equation 9 and Figs. 3 and 4).

7. The maximum leakage current increases less rapidly than the track resistance, except where the track resistance is very low (equation 9 and Fig. 5).

8. If the leakage resistance is small, such as that corresponding to an average concrete roadbed or track embedded in damp soil, the leakage current decreases very rapidly with increase in leakage resistance. For high values of leakage resistance, however, the effect of increasing the leakage resistance on the total leakage current is much less (equation 9 and Fig. 6).

9. If the bus be grounded, as by connecting it to the buried pipe systems the total leakage current is greatly increased (equations 9 and 13 and Fig. 7).

10. With grounded bus the rate of increase in leakage current becomes relatively small as the power house is approached and becomes zero at the negative bus (equation 13 Fig. 7).

11. Where conditions are relatively good increase in leakage resistance has a greater effect in reducing leakage currents if the bus is grounded than when it is ungrounded (Fig. 7).

12. When the conditions are such as to give rise to only moderate leakage currents, the maximum leakage may be more than doubled by grounding the negative bus (equation 13 and Fig. 7, curves *III* and III_1). Where leakage conditions are bad the ratio of increase in leakage current due to grounding is less but the increase is still quite marked (Fig. 7, curves *I* and I_1). These curves emphasize the importance of insulating the negative bus.

13. If the bus be grounded, the maximum leakage increases more rapidly than the feeding distance. For ordinary values of track resistance and leakage resistance this is particularly true for feeding distances up to about 15 000 or 16 000 feet (equation 16 and Fig. 8).

14. For very long feeding distances, such as are frequently encountered on interurban lines, practically all of the current may return by way of the earth (Fig. 8).

15. Potential gradients in the tracks may be materially reduced due to leakage currents, and this reduction is more marked if the bus is grounded (equations 17, 18, and 19, and Fig. 9). Low potential gradients are not in themselves, therefore, a definite indication of good electrolysis conditions, but on the contrary may be due to excessive leakage of current from the tracks. Other factors must be considered, therefore, in interpreting gradient measurements.

16. For any given line the relative value of the gradients for grounded and ungrounded bus is the same for all points on the line. For very long lines the ratio varies practically inversely as the length of the line (equation 20).

17. The reduction of over-all potentials due to leakage currents is relatively much greater in long lines than in short lines and greater with grounded bus than with ungrounded bus. For very long lines and the moderate leakage and track resistance assumed

in plotting the curves of Fig. 10 the over-all potentials are reduced in case of the ungrounded bus to about 20 per cent, and in case of the grounded bus to about 5 per cent of the values they would have if there were no leakage (equations 21, 22, and 23, and Fig. 10). It is evident, therefore, that low over-all potentials, like low potential gradients, are not a positive indication of good electrolysis conditions. It is necessary to know the cause of the low values before their significance can be determined. Certain measures, such as insulating tracks, that can be taken to reduce leakage currents may greatly increase both gradients and over-all potentials, although they would greatly improve electrolysis conditions.

18. If there be no leakage the over-all potential drop is proportional to the first power of the track resistance and to the square of the feeding distance (equation 22 and Fig. 10).

19. If there is leakage and the bus is ungrounded, then as either the track resistance or feeding distance increases indefinitely the over-all potential tends to become proportional to square root of the track resistance and the first power of the feeding distance (equation 21).

20. As the track resistance or feeding distance increases indefinitely the over-all potential, in the case of the grounded bus, tends to become independent of both the track resistance and feeding distance (equation 23 and Fig. 10).

21. If the bus is ungrounded, the intensity of the leakage current at the outer end of the line is less than at the power house end (current returning to the tracks may be regarded as negative leakage current); and the difference is greater the lower the leakage resistance and the greater the length. Hence, operating with trolley negative would, in general, tend to reduce the rapidity with which trouble would become acute. The corrosion would, however, be distributed over a larger territory and its total amount would be substantially unchanged (equation 26 and Fig. 11).

22. As the track resistance is increased indefinitely the potential difference at the outer end of the line approaches a finite maximum value which is $i_o\delta$. A similar result follows from an indefinite increase in the feeding distance (equation 26).

23. Although high leakage resistance lowers the leakage current, as shown by Fig. 16, it also increases the potential difference between tracks and earth. High potential differences are not in themselves, therefore, a definite indication of leakage current (equation 26 and Fig. 11).

24. As the track resistance or feeding distance increases indefinitely, the potential difference between tracks and ground at power house becomes indefinitely large, and the area of the positive zone becomes indefinitely small. Thus, with high track resistance or long feeding distances there will be very severe trouble in a relatively small area (equation 26 and Fig. 12).

25. High track resistances and low leakage resistance both tend to reduce the size of the positive area, although tending to increase the total amount of leakage current, and hence they greatly increase the severity of the electrolysis trouble near the power house. A relatively small positive area, therefore, is an indication of bad electrolysis conditions generally. The length of the positive zone varies from a maximum of 42 per cent of the feeding distance under ideal electrolysis conditions to an indefinitely small value where electrolysis conditions are particularly bad (equations 8 and 26 and Fig. 12).

26. With the bus ungrounded the potential difference at the power house is nearly proportional to the length of the line except for short lines (equation 28 and Fig. 13).

27. With the bus grounded the potential difference at the power house is zero and the change in potential difference is most rapid in the region of the power house.

28. Increase in either the roadbed or the track resistance increases the potential difference at the end of the line (equation 29 and Fig. 14).

29. Leakage resistance is much more influential with respect to potential differences than track resistance (equation 29 and Fig. 14).

WASHINGTON, September 8, 1915.

DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

S. W. STRATTON, Director

TECHNOLOGIC PAPERS OF THE BUREAU OF STANDARDS, No. 64

(Issued January 21, 1916)

DETERMINATION OF BARIUM CARBONATE AND BARIUM SULPHATE IN VULCANIZED RUBBER GOODS

By John B. Tuttle, Associate Chemist

I. PURPOSE OF THE INVESTIGATION

With the advent of buying rubber goods on specifications it became necessary to develop methods which would accurately determine the various constituents. One of the most important determinations is that of total sulphur. In a recent publication of this Bureau [1] the sulphur-bearing constituents of vulcanized rubber goods were mentioned, and a method was given for a quantitative determination of the sulphur which they contain. In this article it was stated that sulphur may occur in various forms including metallic sulphates, usually lead and barium. Many specifications now permit the use of barium sulphate (barytes) without having the sulphur which it contains count as part of the specified total sulphur. It is therefore necessary to be able to determine the percentage of this mineral. This was not at all difficult as long as the rubber compounds contained barium only in the form of the sulphate. When, however, manufacturers

[1] Bureau of Standards Technologic Paper No. 45; J. Ind. Eng. Chem., 7, p. 658 (1915).

began using the carbonate as well as the sulphate the problem became much more complex, since it became necessary to determine both salts of barium in the presence of each other, as well as in the presence of other sulphur-bearing minerals. It is with this phase of the problem that the present article deals.

II. GENERAL CONSIDERATION

The separation of barium carbonate from barium sulphate in the absence of other minerals is readily accomplished by solution of the carbonate in acids, such as hydrochloric, acetic, etc. In rubber compounds, however, this method is not applicable, since lead sulphate may be present, in which case part of the lead sulphate will also be dissolved, and the reaction between the lead sulphate in solution and the barium will cause the precipitation of barium sulphate, and the results obtained will be low. Lead sulphate may be dissolved in ammonium acetate, and it was thought that this disturbing constituent could be eliminated by this procedure, which, however, was found to be too slow and unreliable to be an acceptable method. However, still another procedure is available, viz, transforming the lead sulphate to the carbonate by boiling with alkaline carbonates, and filtering off the soluble sulphates. Sodium carbonate readily converts lead sulphate and barium sulphate [2] into their carbonates; ammonium carbonate reacts with lead sulphate, but tests made here show that it has only a slight effect on barium sulphate. By treatment with ammonium carbonate, we can therefore change the lead sulphate into the carbonate, and then filter the soluble sulphates from the lead carbonate, barium carbonate, and barium sulphate. Calcium and zinc carbonates, which may be present, do not interfere with the desired separation.

III. SAMPLES

The four samples used in this investigation were of known composition, having been compounded and vulcanized at this Bureau. Their composition was as follows:

[2] Noyes and Bray, J. Am. Chem. Soc., 29, p. 151 (1907), state that 80 per cent of barium sulphate is converted into barium carbonate when boiled with an excess of sodium carbonate.

TABLE 1

Composition of Samples

	Compound No. 1	Compound No. 13	Compound No. 16	Compound No. 17
	Per cent	Per cent	Per cent	Per cent
Fine Para rubber	39.6	30.0	20.0	.....
Plantation rubber	.....	.....	.....	40.0
Sulphur	2 5	3.0	2.0	4.0
Litharge	8.6	7.0	8.0	8.0
Zinc oxide	8.7	20.0	20.0	15.0
Sublimed white lead	30.6	.....	.....	.....
Barium carbonate	10.0	.....	.....	10.0
Barium sulphate	.....	20.0	30.0	20.0
Whiting	.....	20.0	20.0	.....
Vaseline	.....	.....	.....	3.0
	100.0	100.0	100.0	100.0

The barium carbonate used in No. 1 and No. 17 was Merck's best quality, and was finely ground before compounding. The barium sulphate was tested and found to contain practically no soluble barium salts. It will be noted that No. 1 contained both barium carbonate and lead sulphate; No. 17 barium carbonate and barium sulphate; while No. 13 and 16 contained barium sulphate only.

IV. THE METHOD EMPLOYED

Schaeffer[3] has shown that the organic matter in rubber can be removed by ignition in an atmosphere of carbon dioxide without change of sulphur to sulphide, or of either to sulphate. Slight reduction of barium sulphate to sulphide may occur during ignition of the rubber, but experience shows that the amount of sulphide formed is practically negligible. The apparatus used for the decomposition of the rubber was practically the same as that used by Schaeffer, the only change being that the sample was placed in a porcelain boat so as to facilitate the removal of the residue from the glass tube. One gram of the rubber was taken for each determination. After ignition and cooling in carbon dioxide the boat was removed, the residue finely ground in an agate mortar, transferred to a 250 cc beaker, and treated with

[3] J. Ind. Eng. Chem., 4, p. 837 (1912).

5 to 10 g ammonium carbonate, 15 to 20 cc of strong ammonia water, and about 50 cc of distilled water. The mixture was boiled for 15 to 30 minutes, filtered, and the precipitate thoroughly washed to remove all soluble sulphates. The residue on the filter paper was washed back into the original beaker with distilled water, about 10 cc of glacial acetic acid and sufficient water to make the total volume of the solution about 100 cc were added. This was heated to boiling and then filtered through the same filter paper as before. By this procedure, lead, barium, calcium, and zinc carbonates pass into solution, while barium sulphate and lead sulphide are not attacked. Hydrogen sulphide was passed into the filtrate, the lead sulphide filtered off, the filtrate heated on the steam bath, and 10 cc of 10 per cent sulphuric acid added. The solution was allowed to stand overnight on the steam bath; the next day the precipitate was filtered off, ignited in a porcelain crucible, cooled, and weighed.

V. RESULTS

TABLE 2

Results of Barium Carbonate Determination

[All results are expressed in percentages of the original sample]

Sample	Constituents	Present	Found			
1	Barium carbonate	10.0	9.72	9.67	9.98	10.02
	Sulphur equivalent to $BaCo_3$	1.63	1.58	1.57	1.62	1.63
17	Barium carbonate	10.0	10.28	9.76	10.73	10.71
	Sulphur equivalent to $BaCo_3$	1.63	1.67	1.59	1.74	1.74
13	Barium carbonate	0.0	0.17	0.08	0.17	0.25
	Sulphur equivalent to $BaCo_3$	0.0	0.03	0.01	0.03	0.03
16	Barium carbonate	0.0	0.29	0.19	0.31	0.09
	Sulphur equivalent to $BaCo_3$	0.0	0.05	0.03	0.05	0.02

VI. DISCUSSION OF RESULTS

The barium sulphate was calculated to barium carbonate, using the factor 0.845. The sulphur in the barium sulphate was also calculated, since it is desirable to know just what error will be introduced if the barium present in the form of the carbonate should be considered as being present as the sulphate. The results on sample No. 1 show that in the presence of lead sulphate (in the

sublimed white lead), barium carbonate can be determined with accuracy, the results, expressed in terms of sulphur, being within 0.05 per cent of the calculated amount. In sample No. 17 we have present both the sulphate and carbonate of barium, and while the results are not as good as those obtained on sample No. 1, they are sufficiently accurate for all practical purposes, the maximum error on sulphur being only 0.11 per cent. Results slightly higher than those calculated must be expected, since samples Nos. 13 and 16, which contain barium sulphate and no barium carbonate, yield small amounts of precipitate by this method, partly in consequence of slight reduction of barium sulphate to sulphide during the ignition of the rubber, and partly on account of the slight action of ammonium carbonate on barium sulphate. These amounts, in themselves, are negligible. It is apparent, therefore, that neither lead sulphate nor barium sulphate interferes appreciably with the determination of barium carbonate by this procedure.

METHOD FINALLY ADOPTED.—The total barium in the rubber compound is determined as barium sulphate by the method for the determination of barytes in use at this Bureau.[4] This method was first suggested by C. E. Waters, and afterwards modified by W. H. Smith and the author. Barium carbonate is determined in a separate sample by the method just described, and an equivalent amount of barium sulphate is deducted from the total barium sulphate. The sulphur in the remaining portion of barium sulphate is calculated, and the total sulphur determination is corrected by this amount.

VII. SUMMARY

A new method is given for the determination of barium carbonate in vulcanized rubber goods. It is shown that this method is sufficiently accurate in the presence of lead and barium sulphates.

The author wishes to acknowledge the assistance of H. A. Ehrman, of this Bureau, who very kindly compounded and vulcanized the samples used in this investigation.

WASHINGTON, November 3, 1915.

[4] Bureau of Standards Circular No. 38, 3d ed., p. 68 (1915); India Rubber World, 51, p. 128 (1914).

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TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 65

DETERMINATION OF OIL AND RESIN IN VARNISH

BY

E. W. BOUGHTON, Associate Chemist

Bureau of Standards

ISSUED FEBRUARY 19, 1916

WASHINGTON
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1916

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DETERMINATION OF OIL AND RESIN IN VARNISH

E. W. Boughton

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I. INTRODUCTION

In spite of the fact that several methods have been published for the determination of oil and resin in varnish, there is a noticeable lack of information regarding the accuracy of the results obtained by such methods, due largely to failure to test the procedures with varnishes of known composition and history. It seemed desirable, therefore, to obtain such information and to devise, if possible, a method which would be satisfactory. While the proposed method has not yielded results which are as accurate or as concordant as might be desired, it is believed that it is sufficiently accurate to be of practical value in varnish analysis. It is shown that several methods to be found in the literature are not reliable for all types of oil varnish.

II. THE MANUFACTURE AND COMPOSITION OF OIL VARNISH

In the manufacture of oil varnish [1] the resins (commonly called "gums" in the trade) are heated until melted, and at the proper time the oil and driers (or oil containing driers) are added. The mass is mixed and heated until, in the judgment of the varnish maker, it is ready to be cooled and thinned. The varnish is filtered and run into settling tanks, where it is aged. The time of heating, temperature, etc., depend upon the nature of the varnish and vary greatly for different kinds.

Many different *resins* are used, among which are kauri, Zanzibar, Pontianak, manila, and rosin (colophony). As a rule, the harder resins are more valuable. The various grades and types of each resin are designated according to size as "bold," "nubs," "seeds," and "dust." The principal *oils* used are linseed oil (refined and treated by various processes) and Chinese wood oil (tung oil). The common *thinners* are turpentine and light mineral oils. Compounds of lead and manganese are used as *driers*, and if rosin is present lime is generally added to harden it. The product obtained by heating a resin at high temperatures, called by Sabin [2] "pyro-copal," is very different in nature from the original resin, and when combined with the oil, imparts to a varnish properties which have so far been obtained only in this way. Further information regarding the manufacture of varnish may be found in many text books.[3]

III. METHODS OF VARNISH EXAMINATION

The usual varnish examination includes the determination of specific gravity, flash point, acid number, amount and nature of the thinner, amount and nature of the ash, a qualitative test for rosin, a drying test on glass, a panel test, in which the drying and rubbing properties and the action of hot and cold water are noted;

[1] In this paper the term "oil varnish" means varnish containing oil and resin. "Short-oil" varnish contains considerable more resin than oil and "long-oil" varnish considerable more oil than resin.

[2] "German and American Varnish Making," M. Bottler and A. H. Sabin (1912).

[3] "German and American Varnish Making," M. Bottler and A. H. Sabin (1912); "The Technology of Paint and Varnish," A. H. Sabin (1904); "The Chemistry of Paint," M. Toch (1907); "The Manufacture of Varnish and Kindred Industries," A. Livache and J. G. McIntosh (1908).

and observation of the consistency and color. In general, such an examination has only a limited value. That a varnish is of poor quality can be determined by these tests, but the superiority of one sample over another when both are of good quality can not be so ascertained, and exposure tests which may require months are then necessary. The only satisfactory method for testing varnishes which are to be used for fine work, such as the varnishing of expensive furniture, is to have the samples tried out by an expert operator skilled in such work. At present, however, neither the practical varnisher nor the chemist can determine by tests the wearing qualities of a sample.

There is a probability that with improved methods of varnish analysis and with the aid of exposure tests on analyzed samples, characteristics may be discovered which will show the relative wearing qualities of samples. With this in view the development of a method for the determination of oil and resin is desirable. The identification of the various resins is a more difficult problem, the possibilities of which are not very promising.

IV. THE DETERMINATION OF OIL AND RESIN

1. GENERAL

The various methods that have been proposed for the estimation of oil and resin may be classified as follows:

Calculation of the oil content from the determined glycerol yield; separation by the use of solvents; and esterification methods, some of which include separation by petroleum ether. Details of these methods will be given in connection with the study of them.

2. PREPARATION OF VARNISHES OF KNOWN COMPOSITION

As previously noted, it seemed especially desirable to test such methods with samples of known composition and history. Accordingly, samples were prepared under conditions which permitted the desired data to be obtained.

Since in the preparation of oil varnish losses occur from both the oil and the resin, to calculate the composition of the varnish it is necessary to assume a certain loss for one or the other, the mag-

nitude of the same depending upon the conditions of manufacture. To determine the loss that occurs when linseed oil is heated and to ascertain whether losses occur from oil and resin when the two are heated together, which are greater than when the two are heated separately, the following experiments were made:

EXPERIMENT 1.—300 g of linseed oil were heated in a beaker at 300° C and the loss in weight noted.

EXPERIMENT 2.—Samples of various resins were heated over a Bunsen burner until completely melted. Samples of melted resin, of linseed oil, and mixtures of approximately equal parts of the two were heated under the same conditions and the losses in weight noted. The results, as given in Table 1, show that under the conditions of manufacture of the special varnishes (see Table 2) losses of from less than 1 per cent to 3 per cent may be assumed to occur in the weight of the oil, and that the calculated losses in weight from the oil-resin mixtures are approximately the same as those obtained by experiment. It has been shown [4] that Chinese wood oil when heated for half an hour at 300° C loses 0.5 per cent in weight. The losses which occur when oils are heated depend not only upon the time and temperature, but also upon the size and shape of the vessel and the amount of exposed surface, so that in estimating the losses in weight occurring during the manufacture, and thereby the oil and resin contents of the finished varnishes, it is to be expected that the figures will be only approximately correct. However, such approximation is all that can be expected in the control of the composition of oil varnish during manufacture.

Four samples of varnish were prepared in the factory.[5] These will be designated in this paper as varnishes A, B, C, and D. Three additional samples were prepared in the laboratory, using other resins than those in varnishes A, B, C, and D. These samples will be designated later as varnishes E, F, and G. Data regarding the constituents and preparation of these samples are shown in Table 2.

[4] Boughton, Proc. Amer. Soc. for Test. Mat., 14, II, 252 (1914).

[5] For the opportunity to prepare these samples and for assistance and advice the writer is indebted to L. P. Nemzek and John Lucas & Co. (Inc.).

TABLE 1

Losses in Weight on Heating Oils, Resins, and Oil-Resin Mixtures

Experiment.	Material.	Time of heating	Temperature	Loss in weight.	
				Determined	Calculated
		Minutes	°C	Per cent	Per cent
1	Linseed oil	60	300	1.7	.....
	Do	120	300	2.7	.....
2	Linseed oil	45	250–275	1.9	.....
	Kauri	45	250–275	6.9	.....
	Linseed oil, 47 per cent; kauri, 53 per cent	45	250–275	3.9	4.5
	Linseed oil	45	250–275	2.2	.....
	Manila	45	250–275	3.7	.....
	Linseed oil, 47 per cent; manila, 53 per cent	45	250–275	3.7	3.0
	Linseed oil	45	250–275	2.2	.....
	Zanzibar	45	250–275	2.9	.....
	Linseed oil, 48 per cent; Zanzibar, 52 per cent	45	250–275	2.9	2.6
	Linseed oil	45	250–275	1.9	.....
	Pontianak	45	250–275	4.3	.....
	Linseed oil, 51 per cent; Pontianak, 49 per cent	45	250–275	3.9	3.1

The composition of each of the finished varnishes was calculated as follows: By deducting from 100 per cent the percentages of ash and thinner, as determined by the usual methods, the sum of the oil and resin contents was obtained. The percentage of oil present was calculated from the amount added, correcting for the estimated losses in weight as shown in Table 2. The percentage of resin was found by difference. The composition of the samples is given in Table 3.

Owing to the approximate nature of the corrections applied for losses in weight of the oils, there may be considerable error in the first decimal place of the figures. The samples analyzed were filtered varnishes, but an examination of the unfiltered varnishes showed amounts of sediment that were too small to cause appreciable errors in the calculations. Further examination of varnishes A, B, C, and D by the usual methods gave the results shown in Table 4.

TABLE 2

Data on Preparation of Special Varnishes

Sample	Constituents	Time of heating[a]	Maximum temperature[a]	Estimated loss in weight	
				Oil	Resin[b]
		Minutes	° C	Per cent	Per cent
A	Rosin, linseed oil, lime, sugar of lead, and benzine.	15	265	(c)	8
B	Rosin, linseed oil, Chinese wood oil, lime, litharge, manganese borate, and benzine.	45	300	2	20
C	Bold Zanzibar, Sierra Leone copal, borate oil,[d] turpentine, and Damar varnish.	(e)	.....	(c)	20
D	Bold Zanzibar, kauri, borate oil[d] and turpentine.	180	290	3	22
E	Manila, linseed oil, litharge, manganese dioxide, and turpentine.	45	260	2	25
F	Congo, linseed oil, litharge, manganese dioxide, and turpentine.	45	260	2	35
G	Pontianak, linseed oil, litharge, manganese dioxide, and turpentine.	45	260	2	28

[a] After addition of the oil.
[b] Includes loss occurring before addition of oil.
[c] Less than 1 per cent.
[d] Linseed oil, containing manganese borate.
[e] Allowed to cool after addition of oil.

TABLE 3

Composition of Special Varnishes

Varnish	Ash (determined)	Volatile thinner (determined)	Oil (calculated)	Resin (calculated)
	Per cent	Per cent	Per cent	Per cent
A	3.9	43.6	3.9	48.6
B	2.4	53.2	31.9	12.5
C	.2	54.0	16.1	29.7
D	.1	47.5	36.1	16.3
E	.04	50.6	26.2	23.2
F	.9	48.0	36.1	15.0
G	.8	50.1	27.6	21.5

TABLE 4

Miscellaneous Data on Special Varnishes

Varnish	Color	Odor	Viscosity (relative)	Acid number	Qualitative test for rosin	
					Color (Liebermann & Storch)	Color (Halphen Hicks [a])
			Seconds			
A	Medium	Mineral oil	6	49.7	Bluish purple	Blue to bluish purple.
B	Dark	do	13	8.6	Purple; more reddish than A.	Do.
C	Light	Turpentine	40	8.1	Brown	Yellow.
D	Dark	do	10	5.1	do	Faint red-purple.

[a] Using phenol and bromine (J. Ind. Eng. Chem., 3, p. 86, (1911).

3. STUDY OF METHODS

(*a*) DETERMINATION OF THE GLYCEROL YIELD WITH SUBSEQUENT CALCULATION OF THE OIL CONTENT.—Lewkowitsch [6] stated that the "boiled oil" content of a varnish can be calculated from the glycerol yield, but gives no figures or references. In order to determine the factor for calculating the oil content of a sample from the glycerol yield the latter was determined with samples of oil by the following method. (Method 1, Table 5.) Four to 5 g of oil were saponified in a beaker with alcoholic potash and after evaporating to a sirupy consistency on the steam bath, water was added, and the solution again evaporated. This was repeated and then about 100 cc of water were added. After the soap was dissolved the fatty acids were liberated with dilute sulphuric acid, a piece of paraffin was added, and the mixture heated on the steam bath for about 10 minutes with stirring. The beaker was cooled and after the fatty acids-paraffin layer had solidified the aqueous solution was decanted through a folded filter into a 300 cc graduated flask. The mass of paraffin and fatty acids was treated with 50 cc of hot water and stirred for a few minutes on the steam bath. The cooling and decantation were repeated and a second washing was made in the same way. A little silver

[6] Chem. Tech. and Anal. of Oils, Fats, and Waxes, 5th ed., III, p. 164 (1915).

sulphate was added and the solution diluted to 300 cc and shaken. The contents were then filtered and 200 cc of the clear filtrate were used for the determination of glycerol by the bichromate method. It is evident from the results recorded under experiments 1 and 2, Table 5, that the glycerol yield will vary according to the amount of heating that linseed oil has undergone and will be approximately 10 per cent. When determinations of the glycerol yields of varnishes A to D were made by this method very erratic results were obtained, most of which, except with varnish B, were higher than those calculated by dividing the oil content by 10. The method was modified so that the beakers containing the soap solution were heated overnight on a steam-heated hot plate and in an air bath at 90° C, but still good results were not obtained. Saponification with 10 per cent aqueous potassium-hydroxide solution was then tried. (Method 2, Table 5.) The saponifications were made in pressure bottles which were heated in a steam bath. The procedure subsequent to the addition of sulphuric acid was the same as is given above. From the results shown in Table 5 it is evident that the use of the factor 10 gives fairly accurate results for oil content of the varnishes except with varnish B, which contained Chinese wood oil. Why the presence of this oil should have such an effect, even though the samples of Chinese wood oils examined showed glycerol yields of approximately 10 per cent, was not ascertained. The difficulty may be due to incomplete saponification, since, according to Ware and Schumann,[7] polymerized Chinese wood oil is not readily saponified. In some of the determinations with varnish B, however, saponification was continued for 20 hours. The calculation from the glycerol yield of the oil content of a varnish containing Chinese wood oil is, therefore, not justified.

(*b*) Separation by the Use of Solvents.—Scott[8] devised a method for the separation of oil and resin by treatment with cold petroleum ether, which is quoted by Holley[9] without comment. Darner[10] stated that Scott's method is not reliable.

[7] J. Ind. Eng. Chem., 7, p. 571 (1915).
[8] Drugs, Oils, and Paints, 15, pp. 132, 219 (1900).
[9] Analysis of Paint and Varnish Products, p. 260 (1912).
[10] North Dak. Agric. Expt. Sta. Paint Bull., 1, No. 6 (1915).

TABLE 5

Glycerol Yields and Calculated Oil Contents

Experiment	Material	Method	Glycerol yield	Glycerol yield X10	Oil present
			Per cent	Per cent	Per cent
1	Raw linseed oil	1	11.14	111.4	
			11.10	111.0	
Average			11.12	111.2	100.00
2	Same oil, after being heated two hours at 275° C.	1	9.62	96.2	
			9.72	97.2	
Average			9.67	96.7	100.00
3	Same as in experiment No. 2	1	9.73	97.3	
			9.67	96.7	
Average			9.70	97.0	100.00
4	Chinese wood oil	2	10.61	106.1	
			10.63	106.3	
Average			10.62	106.2	100.00
5	Same oil, after being heated two hours at 170° C.	1	10.08	100.8	
			10.15	101.5	
Average			10.12	101.2	100.00
6	Chinese wood oil used in making varnish B	2	10.42	104.2	100.00
7	Varnish A	1	0.42	4.2	
			0.53	5.3	
			0.51	5.1	
Average			0.49	4.9	3.9
8	Varnish B	1	2.40	24.0	
			1.71	17.1	
			1.82	18.2	
			2.31	23.1	
			2.50	25.0	
			2.56	25.6	
Average			[a] 2.53	[a] 25.3	31.9
9	Varnish C	2	1.77	17.7	
			1.76	17.6	
Average			1.77	17.7	16.3

[a] Average of last two determinations.

TABLE 5—Continued

Glycerol Yields and Calculated Oil Contents—Continued

Experiment	Material	Method	Glycerol yield	Glycerol yield×10	Oil present
			Per cent	Per cent	Per cent
10	Varnish D	2	3.66	36.6	
			3.38	33.8	
			3.41	34.1	
			3.38	33.8	
			3.57	35.7	
Average			3.48	34.8	36.1
11	Mix ready for thinning, taken during manufacture of varnish B.	2	5.43	54.3	73

Bochand and Gillet [11] outlined a scheme for varnish analysis in which they endeavored to separate oil and resin by the Gladding method, as modified by Hübl and Stadtler, based on the difference in solubility of the silver salts. Their results were unsatisfactory, only 19.5 per cent of oil being obtained from a sample containing 25 per cent. Lewkowitsch [12] has shown that the Gladding method and modifications thereof do not give reliable results. In the present investigation no tests were made on this method.

Livache and McIntosh [13] stated that the simplest and most exact method for the determination of oil and resin is to treat a dried film with an appropriate solvent, the weight of oil being calculated from the weight of insoluble linoxyn, allowing for an absorption of 15 to 16 per cent of oxygen by the linseed oil.

A method was devised by Voorhees,[14] which is as follows: The varnish is treated with a small amount of chloroform and a large amount of petroleum ether, the precipitate is separated and weighed. The petroleum ether solution is evaporated to dryness, and the residue is oxidized by heating for eight days at 100° C and is then extracted with chloroform. The precipitate is called "hard gums," and the chloroform extract after oxidation is

[11] Proc. Eighth Intern. Cong. Applied Chem., 12, pp. 7–12 (1912).

[12] Oils, Fats, and Waxes, 5th ed., I, p. 625 (1913).

[13] Manufacture of Varnishes and Kindred Industries, II, p. 183 (1908).

[14] This method was published in Bull. 109, Bureau of Chemistry, Dept. of Agr., but was omitted from revised edition.

assumed to be "gums soluble in petroleum ether." The part insoluble in chloroform is assumed to be oxidized oil.

Of the above methods, that of Voorhees appeared to be the most promising. Preliminary analyses [15] of varnishes A to D by this method yielded results which were not in accord with the calculated composition. Tests were then made on each step of the method. In some experiments the varnish was treated with a mixture of 2 cc of chloroform and 75 cc of petroleum ether [16] (method 1, Table 6), and in others with petroleum ether alone (method 2, Table 6), the precipitates in each case being analyzed by the esterification method, outlined later on page 23, and the results corrected as indicated on page 26. The results obtained are shown in Table 6. Although the amount of precipitate analyzed was so small that the results are only approximate, it is evident that much oil is precipitated with the resin, especially in the presence of Chinese wood oil. These results indicate that the same precipitation of oil would occur in any method which involves direct treatment of a varnish with petroleum ether.

To determine the accuracy of the last step in Voorhees's method, i. e., the extraction of the oxidized film with chloroform to remove the gums, the following experiments were made. The petroleum ether-chloroform solutions obtained in experiments 1 and 2, Table 6, after separation of the precipitates, were flowed on strips of filter paper, which were then placed in an air bath and heated for eight days at 100–110° C. They were then extracted with chloroform at the boiling point. The amounts of extracts obtained, calculated as percentages of the varnishes, are shown in Table 7, experiments 1 and 2.

Some experiments were made on the extraction of films of oxidized oils and varnishes, omitting the treatment with petroleum ether (method of Livache and McIntosh). One g samples of heated linseed oil and Chinese wood oil were dissolved in chloroform and the solution was flowed on filter paper. The sheets were heated for seven days at 100–110° C in an air bath and then extracted with chloroform at the boiling point. Samples of varnishes A to D were similarly treated. Further extrac-

[15] Analyses by F. A. Wertz.

[16] The portion distilling between 40–65° C.

tion with benzene of the film of varnish D yielded an additional extract of only 0.5 per cent. To determine whether the resin could be extracted with chloroform from a film produced by oxidizing the fatty and resin acids, samples of varnishes C and D were saponified in shallow dishes, the acids were liberated by the addition of hydrochloric acid, and the mixture evaporated to a pasty consistency and mixed with sand. The dishes were heated on a steam-heated hot plate for eight days, and the mass was then extracted with chloroform at the boiling point. It is evident from all the results shown in Table 7 that, except with varnish A, which contained 48 per cent of rosin, only a portion of the resinous matter present was extracted. As methods of analysis, neither that of Voorhees nor that of Livache and McIntosh appears reliable.

TABLE 6

Amounts and Composition of Precipitates Obtained By Voorhees' Method

Experiment	Varnish	Method	Precipitate	Composition of precipitates			
				Resin		Oil	Ash
				Resin acids + unsaponifiable matter	By difference		
			Per cent	Per cent	Per cent	Per cent	Per cent
1	C	1	18.9	65	71	29	.....
2	D	1	7.2	50	54	46	.....
3	B	2	25.3	[a] 28	[a] 24	68	8
4	C	2	23.5	65	69	31	.....
5	D	2	8.5	54	.....	[b] 46	.....
6	H [c]	2	21.8	49	55	41	4

[a] Rosin. [b] By difference. [c] A mixture of varnishes B and C containing 10 per cent of Chinese wood oil.

TABLE 7

Extraction of Oxidized Films

Experiment	Material	Time of oxidation	Time of extraction	Extract	Resin present
		Days[a]	Hours	Per cent	Per cent
1	Portion of varnish C soluble in petroleum ether; $CHCl_3$ mixture.	5	6	5.9	[b] 16
2	Portion of varnish D soluble in petroleum ether; $CHCl_3$ mixture.	5	6	7.7	[b] 13
3	Heated linseed oil	7	3	3.5	
				4.5	
Av				4.0	None.
4	Heated Chinese wood oil	7	3	1.7	
				2.3	
Av				2.0	None.
5	Varnish A	5	6	53.3	
		7	6	53.8	48.6
6	Varnish B	5	3	6.3	
		6	5	6.6	
		7	3	5.4	
		7	6	5.5	12.5
7	Varnish C	5	3	13.1	
		6	6	13.1	
		7	3	10.3	
		7	6	10.5	29.7
8	Varnish D	1	3	12.6	
		1	5	13.6	
		2	3	9.8	
		2	6	10.3	
		4	3	6.6	
		5	6	7.1	
		6	3	6.4	
		6	5	6.8	
		7	3	5.2	
		7	5	5.3	16.3
9	Fatty acids, resin acids, and unsaponifiable matter of varnish C.	5	6	[c] 11.2	[c] 29.7
10	Fatty acids, resin acids, and unsaponifiable matter of varnish D.	5	5	[c] 3.9	[c] 16.3

[a] One day = 24 hours.
[b] Total resin in varnish minus resin precipitated by petroleum ether.
[c] Per cent of varnish.

(*c*) ESTERIFICATION METHODS.—The methods most commonly used for the sepration of fatty oil and rosin are those based upon the fact that in the presence of a dehydrating agent fatty acids and ethyl alcohol react to form esters, while rosin acids do not.

In Twitchell's [17] method dry hydrochloric-acid gas is passed through a solution of the mixed acids in absolute ethyl alcohol. In Wolff's [18] method a mixture of concentrated sulphuric acid and a solution of the mixed acids in absolute ethyl or methyl alcohol is boiled for two minutes. In both methods the subsequent procedure is as follows:

The mixture of fatty acid esters and rosin acids is dissolved in petroleum ether. The rosin acids are separated by treatment with a solution of potassium hydroxide and subsequently liberated and weighed, or an alcoholic solution of the fatty acid esters and rosin acids is titrated with standard alkali, the amount of rosin present being calculated by assuming that 1 cc of normal alkali equals 0.346 g of rosin. When this method is used for the analysis of varnishes which contain resins that yield material insoluble in petroleum ether, the insoluble matter must be separated. Also, if appreciable amounts of resin (other than rosin) remain dissolved in the petroleum ether, the volumetric method can not be used, since the various resins have different neutralization values.[19]

In attempting to determine rosin in Kauri varnish, Gill [20] saponified the nonvolatile portion with alcoholic potash and liberated the fatty and resin acids together. He then separated the fatty acids from the resin acids by the Twitchell method. He gave no figures to show the accuracy of the separation by this method.

Holley [21] published a method of varnish analysis which includes the separation of oil and resin by the Twitchell method, but gave no figures to show the accuracy of the results. The amount of resin present was assumed to be equal to the weight of the resin acids obtained, and, since this is approximately true only with rosin and not with other resins, the method, as described, can not be considered reliable.

Lewkowitsch [22] obtained low yields of what he called "gum resin" on treating copal and mastic by the Twitchell method and considered the latter useless for varnish analysis.

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[17] J. Soc. Chem. Ind., **10**, p. 884 (1891).
[18] Chem. Ztg., 38, pp. 369–370, 382–383, 430 (1914).
[19] See table in Lewkowitsch, Chem. Tech. of Oils, Fats, and Waxes. 5th ed., **III**, p. 165 (1915).
[20] J. Amer. Chem. Soc., 28, p. 1723 (1906).
[21] Analysis of Paint and Varnish Products, p. 259 (1912).
[22] Oils, Fats, and Waxes, 4th ed., **III**, p. 127 (1909).

McIlhiney [23] stated that the oil and resin in a varnish can not be separated directly by any solvent, and devised a method (for the separation of oil, rosin, and "hard gums") in which the varnish is saponified with alcoholic potash, the alcohol distilled off, and absolute alcohol is added to the residue. The saponification number is determined by titrating the excess of alkali with a solution of acetic acid in absolute alcohol. The fatty and resin acids are then liberated by adding the calculated amount of acetic acid solution. Petroleum ether is added and then water, producing a precipitate which McIlhiney terms "hard gum." The fatty and rosin acids remaining dissolved in the petroleum ether are subsequently separated by the Twitchell method. If fatty acids from oxidized oil are precipitated with the "hard gum," they are separated by treating the precipitate with 85 per cent alcohol. No results by this method are recorded. Lewkowitsch [24] stated that McIlhiney's method "can only lead to approximate results." Darner,[25] in using McIlhiney's method with a varnish containing 31.8 per cent of oil, obtained 38.1 per cent. He erroneously stated that McIlhiney recommends the use of *absolute* alcohol for the removal of oxidized fatty acids from the precipitated gum. Darner stated that in McIlhiney's method Chinese wood oil, if present, will be precipitated with the gum, and also that the manipulation of the method is difficult, the separation of the precipitated gum being very troublesome. The same difficulty has been noted by the author.

Darner devised the following method:

Three to four grams of varnish are spread out on an Adams filter coil which has been dried and weighed along with an extraction thimble. The coils absorb water rapidly and for this reason the coils and thimble must be weighed in a weighing bottle. The varnish is best weighed and added to the coil from a dropping bottle. The coil is then held in the mouth of a 300 cc weighed Erlenmeyer flask, and 100 cc of petroleum ether, 0.670 sp. gr., added slowly. A large percentage of the varnish will be washed out of the coil by this treatment. The coil is then placed in the extraction thimble and extracted for 36 hours or until extraction is complete; 150 cc of petroleum ether, 0.670 sp. gr., is added to the flask and the flask cooled to 3° C, until the gums settle and the liquid is clear. The liquid containing the oils and rosin is poured off the gums and the flask washed several times with petroleum ether and the washings added to the original

[23] Proc. Amer. Soc. for Test. Mat., 8, p. 596 (1908).
[24] Chem. Tech. Oils, Fats, and Waxes, 5th ed., III, p. 166 (1915).
[25] N. Dak. Agr. Expt. Sta. Paint Bull., 1, No. 6 (1915).

petroleum-ether extract. The Erlenmeyer flask and thimble are then dried at 105° C to constant weight. The increase in weight of the flask and thimble minus the weight of the metallic driers represents the weight of hard gums in the varnish. The extract from the gums is freed of the petroleum ether, saponified with ½N alcoholic potash and the unsaponifiable matter extracted with ether. The rosin and fatty acids are then released with ½N hydrochloric acid and extracted with ether. The acids are then freed of the ether and the rosin determined by Twitchell's method.

With 13 samples of varnish Darner obtained remarkably accurate results for oil, rosin, and gum. He does not state whether the rosin was determined gravimetrically or volumetrically. He records the figures representing the amounts of oil, rosin, and gum (estimated and found) to hundredths of 1 per cent. In view of what has been said regarding the impossibility of ascertaining exactly how much the oil and resin, respectively, lose in weight during manufacture, this does not appear justifiable.

Preliminary to the study of the esterification methods the following experiments were made. The yields of fatty acids and of unsaponifiable matter [26] from raw linseed oil and from the same oil after heating for one hour at 275° C were determined. The results, as given in Table 8, show that to calculate the amount of oil from the fatty acid yield of a varnish, the factor 1.06 should be used, which, for the purpose of varnish analysis, is not materially different from that obtained with raw linseed oil, 1.07.

TABLE 8

Yields of Fatty Acids and Unsaponifiable Matter from Linseed Oil

Material	Unsaponifiable matter	Fatty acids
	Per cent	Per cent
Raw linseed oil	1.3	92.8
	1.2	93.1
Average	1.25	92.95
Same oil after heating 1 hour at 275° C	1.1	94.0
	1.1	94.2
Average	1.1	94.1

[26] The term "unsaponifiable matter," as used in the experimental part of this paper, means the material extracted by ether after saponification with alcoholic potash, the ether solution being subsequently washed with water. In the analyses of varnishes the amounts of resin acids and unsaponifiable matter obtained frequently varied greatly with the same sample, so that, while the sum of the two serves as a check on the amount of resin present, the ratio of the two has practically no significance.

The Wolff method for the separation of oil and rosin is shorter and simpler than the Twitchell method. The two methods were compared first with fatty acids prepared from raw linseed oil, the solution of the esters and unesterified acids being titrated with standard alkali and the results calculated as "acid number" (milligrams of potassium hydroxide per gram of fatty acids taken). The acid (neutralization) value of linseed-oil fatty acids is 196–199, so that the results given in Table 9, experiment 1, show that by the Twitchell method 98.5 per cent of the fatty acids was esterified and by the Wolff 96.9 per cent. The two methods were further compared by analyses of a mixture of rosin and linseed oil and of the nonvolatile portion of varnish D, using ether as solvent after esterification and determining the resin acids gravimetrically. For the purposes of varnish analysis the two methods are in substantial agreement. (See Table 9 (2).) The reason for the excessive percentage of oil obtained in the analysis of the nonvolatile portion of varnish D will be mentioned later.

TABLE 9

Results by Twitchell and Wolff Methods

(1) ESTERIFICATION OF LINSEED OIL FATTY ACIDS AND SUBSEQUENT TITRATION

Material	Method	Acid number after esterification
Raw linseed oil fatty acids	Twitchell	2.7
		3.3
	Average	3.0
	Wolff[a]	6.6
		5.7
	Average	6.15

[a] Sometime after the completion of the experimental work of this paper an experiment was made on the esterification of linseed oil fatty acids by Wolff's method, using absolute methyl alcohol. An average acid number of 4.1 was obtained.

(2) ESTERIFICATION AND GRAVIMETRIC DETERMINATION OF OIL AND RESIN IN MIXTURES

Material and method	Fatty acids	Oil		Resin		
		Present	Found	Present	Found	
					By difference	Resin acids +unsapon. matter [a]
Linseed oil and rosin:	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Twitchell	48.0		51.4		48.6	47.4
	48.2		51.6		48.4	47.0
Average	48.1	51.5	51.5	48.4	48.5	47.2
Wolff	49 6		53.1		46.9	45.6
	49.7		53.2		46.8	47.0
Average	49.65	51.6	[b] 53.15	48.4	46.85	46.3
Nonvolatile portion of varnish D:						
Twitchell	66.5		70.5		29.5	29.6
	67.6		71.7		28.3	28.9
Average	67.05	69	[c] 71.1	31	28.9	29.25
Wolff	66.9		70.8		29.2	28.5
	67.7		71.8		28.2	27.6
Average	67.3	69	[c] 71.3	31	28.7	28.05

[a] Corrected for unsaponifiable matter in oil. [b] Fatty acids×1.07. [c] Fatty acids×1.06.

McIlhiney's method was used for the analysis of varnishes C and D, and gave the results shown in Table 10. As neither of these samples contained rosin, whereas the amounts of resin acids [27] obtained from the petroleum ether [28] solution were 5 and 4.8 per cent, respectively, it is evident that as a method for the separation of "hard gum" from rosin the procedure is not reliable. The result for total oil in C is too high and in D is too low. If the treatment with 85 per cent alcohol to remove the oxidized fatty acids from the "hard gums" had been omitted in the analysis of C, the results for total oil and total resin would have been fairly close to the amounts actually present. On samples of unknown composition, however, one can not tell whether this step should be included. The analysis of the material insoluble in petroleum

[27] Determined gravimetrically. [28] The portion distilling between 40–65° C.

ether, the results of which are shown in Table 11, was made by the method outlined later on page 23, applying the correction mentioned on page 26. Owing to the small amount of material analyzed and the approximate nature of the correction, the figures obtained must be considered as approximations, but it is clearly shown that much less oil (fatty acids) is precipitated with the resin than in Voorhees's method (see p. 12), in which the preliminary saponification and liberation of the fatty and resin acids are omitted.

TABLE 10

Results with McIlhiney's Method

Experiment	Varnish	Oil			
			Found		
		Present	Fatty acids soluble in petroleum ether x 1.06	Fatty acids insoluble in petroleum ether and soluble in 85 per cent alcohol x 1.06	Total oil
		Per cent	Per cent	Per cent	Per cent
1	C	16.1	15.3	3.8	19.1
2	D	36.1	27.9	2.3	30.2

Experiment	Varnish	Resin					
			Found				
		Present	Insoluble in petroleum ether and in 85 per cent alcohol	Soluble in petroleum ether		Total resin	Total resin by difference
				Resin acids	Unsaponifiable matter		
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1	C	29.7	14.0	5.0	7.2	26.2	26.7
2	D	16.3	12.8	4.8	5.2	22.8	22.2

TABLE 11

Results of Analysis of Matter Insoluble in Petroleum Ether (Varnish C)

		Per cent.
Total precipitate was 18.2 per cent of varnish.	Fatty acids	7
	Resin, by difference	93
	Resin (resin acids plus unsaponifiable matter)	87

TABLE 12

Results of Analysis of Varnish by Darner's Method

Experiment	Material	Oil		Resin					
					Found				
		Present	Found fatty acids x 1.06	Present	Insoluble in petroleum ether	Soluble in petroleum ether		Total resin	Total resin by difference
						Resin acids	Unsaponifiable matter		
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1	C	16.1	16.3	29.7	15.1	4.4	10.3	29.8	29.5
2	D	36.1	32.2	16.3	13.1	4.2	4.2	21.5	20.2
3	E	26.2	20.2	23.2	16.4	5.9	5.9	28.2	29.2
4	Sierra Leone Copal	0.0	1.9	100.0	92.6	1.9	3.5	98.0	98.1
5	Pontianac	0.0	0.4	100.0	91.0	4.2	1.8	97.0	99.6

Darner's method was used for the analysis of varnishes C, D, and E, the resin acids from the petroleum-ether [29] solution being determined gravimetrically. None of these samples contained rosin. The results as given in Table 12 show that with the "short oil" varnish, C, the results for total resin and total oil are very satisfactory, but for the "long oil" varnish, D, and varnish E, the results for oil content are too low. Also, in all these analyses, appreciable amounts of resin acids were obtained from the petroleum-ether solution, which indicates that the method, as a means for accurate separation of "gum" and rosin, is not reliable.

Samples of two resins, Sierra Leone Copal, and Pontianac, were melted to complete fusion, and 2 g portions were analyzed by Darner's method. The results as given in Table 12 show that considerable resin remains dissolved in the petroleum ether, which in a varnish analysis by this method would not be weighed as "gum."

Since the use of petroleum ether in esterification methods gave results for oil contents, which, with "long oil" varnishes, were low, the following method, including esterification by the Wolff method and the use of ethyl ether instead of petroleum ether, was

[29] The portion distilling between 55–80°C. Sp. gr. at 15.6/15.6° C.=0.671.

used for the analysis of varnishes A to G. Approximately 4 g of varnish were placed in a flask and about 25 cc of water added. The mixture was boiled until the volume of the water was about 10 cc, thus removing the volatile thinner. Alcoholic potash and benzene were added and the flask placed on the steam bath for one hour. The unsaponifiable matter was partially removed by one extraction with ether. After hydrochloric acid had been added, the fatty acids, resin acids, and remaining unsaponifiable matter were dissolved in ether and were recovered from the ether solution and dried. They were then treated with absolute ethyl alcohol and sulphuric acid. After dilution with 10 per cent sodium-chloride solution, the resin acids, fatty acid esters, and unsaponifiable matter were extracted with ether and the resin acids removed by treatment with a solution of potassium hydroxide. Hydrochloric acid was added to the resin soap solution and the resin acids extracted by ether. After washing the ether with water the resin acids were recovered, dried at 110° C and weighed. The fatty acid esters and unsaponifiable matter were recovered from the ether solution and were treated with alcoholic patash. The unsaponifiable matter was removed by repeated extractions with ether. The united ether solutions were washed with water and added to the ether solution of unsaponifiable matter previously obtained. The ether was distilled off and the unsaponifiable matter dried at 110° C and weighed. The solution of the soaps of the fatty acids was treated with hydrochloric acid, the fatty acids were dissolved in ether and, after the ether solution had been washed with water, were recovered, dried at 110° C, and weighed. It had been found by preliminary experiments that it is almost impossible to remove all the unsaponifiable matter previous to esterification. It was also found that heating the fatty acids from linseed oil for one hour in air at 110° C caused a gain in weight of only 0.3 per cent. The lack of concordance in duplicate analyses being so much greater than this, heating in carbon dioxide was omitted.

The results are shown in Table 13. With varnish A the results are satisfactorily accurate. With varnish B the results for resin content are somewhat too high. With varnishes C to G, which

contained resins other than colophony, the results for resin contents are too low, showing that the material weighed as fatty acids must have contained some resinous matter. With the possible exception of varnish B, the results for resin contents obtained by adding the percentages of resin acids and unsaponifiable matter are in fair agreement with those obtained by estimating the resin by difference. That the removal of nearly all of the unsaponifiable matter before esterification does not prevent the contamination of the fatty acids with resinous matter is shown by the results recorded under experiment 8, Table 13, in which the soap solution after the first saponification was extracted four times with ether.

TABLE 13

Analysis of Varnishes

Experiment	Varnish	Fatty acids	Resin acids	Unsaponifiable matter	Oil		Resin		
					Present	Found, fatty acids × 1.06	Present	Found	
								Unsaponifiable matter + resin acids	By difference
		Per ct	Per ct	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1	A	4.4	34.8	12.0		4.7		46.8	47.8
		4.6	35.2	12.6		4.9		47.8	47.6
Av.		4.5	35.0	12.3	3.9	4.8	48.6	47.3	47.7
2	B	28.5	10.7	3.3		30.2		14.0	14.2
		28.3	7.9	8.4		30.0		16.3	14.4
		29.8	6.0	7.9		31.6		13.9	12.8
		30.2	9.1	4.3		32.0		13.4	12.4
Av.		29.2	8.4	6.0	31.9	31.0	12.5	14.4	13.4
3	C	17.8	13.8	12.2		18.9		26.0	26.9
		17.5	13.5	15.2		18.6		28.7	27.2
		19.8	13.1	12.3		21.0		25.4	24.8
		16.8	10.9	16.9		17.8		27.8	28.0
		17.9	14.0	11.9		19.0		25.9	26.8
		.....	13.9	13.3		.....		27.2	.....
		.....	12.6	14.8		.....		27.4	.....
Av.		18.0	13.1	13.8	16.1	19.1	29.7	26.9	26.7

TABLE 13—Continued

Analysis of Varnishes—Continued

Experiment	Varnish	Fatty acids	Resin acids	Unsaponifiable matter	Oil		Resin		
					Present	Found, fatty acids × 1.06	Present	Found	
								Unsaponifiable matter + resin acids	By difference
		Per ct	Per ct	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
4	D	35.1	3.9	13.0		37.2		16.9	15.0
		33.4	4.6	12.3		35.4		16.9	16.8
		36.6	5.3	8.9		38.8		14.2	13.4
		34.6	4.5	11.4		36.7		15.9	15.5
		35.0	4.6	10.3		37.1		14.9	15.1
Av.		34.9	4.6	11.2	36.1	37.0	16.3	15.7	15.2
5	E	25.8	13.3	7.5		27.9		20.8	21.5
		24.8	13.6	6.9		26.9		20.5	22.5
Av.		25.3	13.5	7.2	26.2	27.4	23.2	20.7	22.0
6	F	35.8	3.0	10.9		37.9		13.9	13.2
		34.9	3.3	8.3		37.0		12.6	14.1
Av.		35.4	3.2	9.6	36.1	37.5	15.0	13.3	13.7
7	G	27.4	11.6	7.0		29.0		18.6	20.1
		27.8	11.5	7.5		29.5		19.0	19.6
Av.		27.6	11.6	7.3	27.6	29.3	21.5	18.8	19.9
8	C [a]	17.4	14.2	12.9		18.3		27.1	27.5
		17.1	13.8	12.2		18.1		25.0	27.7
Av.		17 3	14.0	12.6	16.1	18.2	29.7	26.6	27.6

[a] Modified method.

To determine the existence and magnitude of errors due to the contamination of the fatty acids with resinous matter, the products obtained by heating various resins at about 300° C were analyzed by the method. Samples of the melted resins taken during the manufacture of varnishes C and D were also analyzed. The yields of material which in a varnish analysis would be weighed as "fatty acids," as shown in Table 14, varied from 3.1 to 10.6 per cent. Were there no other error in the method it

would appear safe to assume that if the yields of resin obtained be multiplied by 1.07, results that are correct to within 5 per cent of the amounts present would be obtained. The average results obtained with varnishes C to G, when thus corrected, are shown in Table 15, method 1. However, since there was considerable lack of concordance in duplicate determinations, and since this correction is not applicable to rosin, if present, it seems preferable as a general procedure to assume that the percentage of fatty acids obtained equals the percentage of oil in the sample, making no further correction. The average results with varnishes A to G, when thus calculated, as shown in Table 15, method 2, are correct to within 7 per cent of the predominating ingredient of the ash-free nonvolatile portion, and the greatest error for percentages of oil and of resin, when expressed as percentage of the varnish, is 2.2 per cent.

Some analyses were made by the method outlined on page 23, but varying the solvent; e. g., the proportions of ethyl ether and petroleum ether, used to treat the mixture of fatty acid esters and resin acids after esterification. It was hoped that a mixture would be found which would give accurate results without the use of a correction factor. The results, as given in Table 16, show that an appropriate mixture for a long oil varnish, D, gave erroneous results with the short oil varnish, C.

TABLE 14

Analysis of Melted Resins

Resin	Yield of material which would be weighed as fatty acids	Resin	Yield of material which would be weighed as fatty acids
	Per cent		Per cent
Resins of varnish C	10.6	Sierra Leone copal	7.1
Resins of varnish D	4.8	Kauri	4.7
Pontianak	3.1	Zanzibar	3.1
Manila	4.0	Dammar [a]	6.6

[a] Not melted.

TABLE 15

Average Results from Table 13, Corrected

Varnish	Oil			Resin			
	Present	Found		Present	Found		
		Method 1	Method 2		Method 1	Method 2	Resin acids+ unsapon. matter ×1.07
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
A	3.9	.....	4.5	48.6	.....	48.0	.....
B	31.9	.....	29.2	12.5	.....	14.7	.....
C	16.1	17.2	18.0	29.7	28.6	27.8	28.8
D	36.1	35.9	34.9	16.3	16.5	17.5	16.9
E	26.2	25.9	25.3	23.2	23.5	24.1	22.1
F	36.1	36.4	35.4	15.0	14.7	15.7	14.2
G	27.6	27.8	27.6	21.5	21.3	21.5	20.1

TABLE 16

Effect of Varying Solvent Used after Esterification

Experiment	Varnish	Solvent	Oil		Resin				
			Present	Found, fatty acids ×1.06	Present	Found			
						Insoluble resin	Soluble resin acids+ unsapon. matter	Total resin	Total resin by difference
			Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1	D	Ether	36.1	37.4	16.3	0.0	15.3	15.3	15.0
				37.9			14.5	14.5	14.5
Average				37.7			14.9	14.9	14.7
2	D	Ether 4/5, petroleum ether 1/5	36.1	34.7	16.3	0.0	17.6	17.6	17.7
				35.4			16.1	16.1	17.0
Average				35.1			16.9	16.9	17.3
3	D	Ether 1/2, petroleum ether 1/2	36.1	34.7	16.3	3.9	13.2	17.1	17.7
				34.5		3.4	14.2	17.6	17.9
Average				34.6		3.7	13.7	17.4	17.8
4	D	Petroleum ether	36.1	34.3	16.3	9.3	8.6	17.9	18.1
				34.2		9.4	8.0	17.4	18.2*
Average				34.3		9.4	8.3	17.7	18.1
5	C	Ether 4/5, petroleum ether 1/5	16.1	20.0	29.7	7.6	18.6	26.2	25.8

(*d*) Discussion of Esterification Methods.—The results obtained with the short oil varnish, C, using the methods of Darner and McIlhiney, indicate that with certain samples these methods will give accurate results for percentages of oil and resin. With the long oil varnish, D, in which the mix was bodied by heating for several hours, these methods gave very poor results. The chief error in using methods which involve the use of petroleum ether lies in the assumption that the precipitates obtained with all samples consist of all the "gum" present and no oil.

Assuming that the neutralization values of the portions of the hard resins that are dissolved by petroleum ether are low, the volumetric determination of rosin in the presence of other resins may give fairly accurate results. In many cases analysts may have obtained accurate results by various methods for the determination of oil, rosin, and "hard gum," because of compensating errors.

The changes which occur when varnish is aged must be considered in connection with the determination of oil and resin. The oil may oxidize and thereby gain in weight, causing a yield of fatty acids which will be greater than that from the freshly prepared varnish. Turpentine, if present, may change so as to yield nonvolatile matter which will appear on analysis as resin or oil, probably as the former. Unless the varnish is in closed containers the volatile thinner will, of course, evaporate, causing a higher yield of nonvolatile matter.

V. PROPOSED METHOD

The following method, already outlined on page 23, is proposed for the determination of oil and resin, since in the experimental work it was found to be the most reliable as a general method for different types of oil varnish. The essential steps in the process are outlined in the following diagram (Fig. 1). In the following description of the method, as used by the author, the exact details may not be essential, but are given as a guide for those not familiar with varnish analysis.

To 3 to 4 grams of varnish in a flask add about 25 cc of water and boil until the volume of the water is about 10 cc. This removes nearly all of the volatile thinner. Add 25 cc of 0.5 N

alcoholic potash and 25 cc of benzene (C_6H_6) and boil under a reflux condenser for one-half hour. Evaporate the solution to about 15 cc and add about 10 cc of alcohol. Transfer the mixture completely to a separatory funnel, washing the flask with water and ether, using a policeman if necessary. After diluting with water to about 100 cc add 100 cc of ether and shake. (At this point, and with all subsequent extractions with ether, add alcohol in 2 cc portions, if necessary, to cause the layers to separate.) Having drawn off the aqueous layer, wash the ether layer three times with water, and finally transfer the ether solution, containing part of the unsaponifiable matter, to a tared flask for future use if so desired (see diagram). To the combined soap solution and washings add an excess of hydrochloric acid and extract twice with 50 cc of ether. Discard the aqueous layer, wash the combined ether solution with water, transfer it to a flask, and distil off the ether. To the dry residue add 20 cc of absolute alcohol and 20 cc of a mixture of 1 volume of sulphuric acid and 4 volumes of absolute alcohol and boil the mixture for two minutes under a reflux condenser. Completely transfer the contents of the flask to a separatory funnel (a small amount of insoluble matter may be obtained here), washing the flask with water and ether. Add 100 cc of ether and after agitation add 100 cc of 10 per cent sodium-chloride solution and again agitate. Draw off the aqueous layer, extract it with 50 cc of ether, and wash with water the combined ether solutions. To the latter add 50 cc of 0.2 N potassium hydroxide solution and 10 cc of alcohol, shake the mixture, and draw off the lower layer into a second funnel. Wash the ether layer with 50 cc of water containing 5 cc of 0.2 N potassium hydroxide solution and 5 cc of alcohol. If, on treating the ether solution of the resin acids and fatty acids esters with the potassium hydroxide solution, some insoluble matter is formed, it is due to the insolubility of the soaps of the resin acids, and such matter is carried through into the final resin soap solution, where it is decomposed with acid. Extract the combined aqueous portions with two 50 cc portions of ether and finally wash the combined ether solutions (containing the ethyl esters of the fatty acids) with water. Distil off the ether and boil the residue with 25 cc of 0.5 N alcoholic potash for one-half hour under a reflux condenser. Transfer the

solution to a separatory funnel, washing the flask with ether and water, and extract the soap solution four times with ether. Wash the combined ether solution twice with water and add it to the first ether solution of unsaponifiable matter obtained. (The determination of unsaponifiable matter may be omitted unless a check

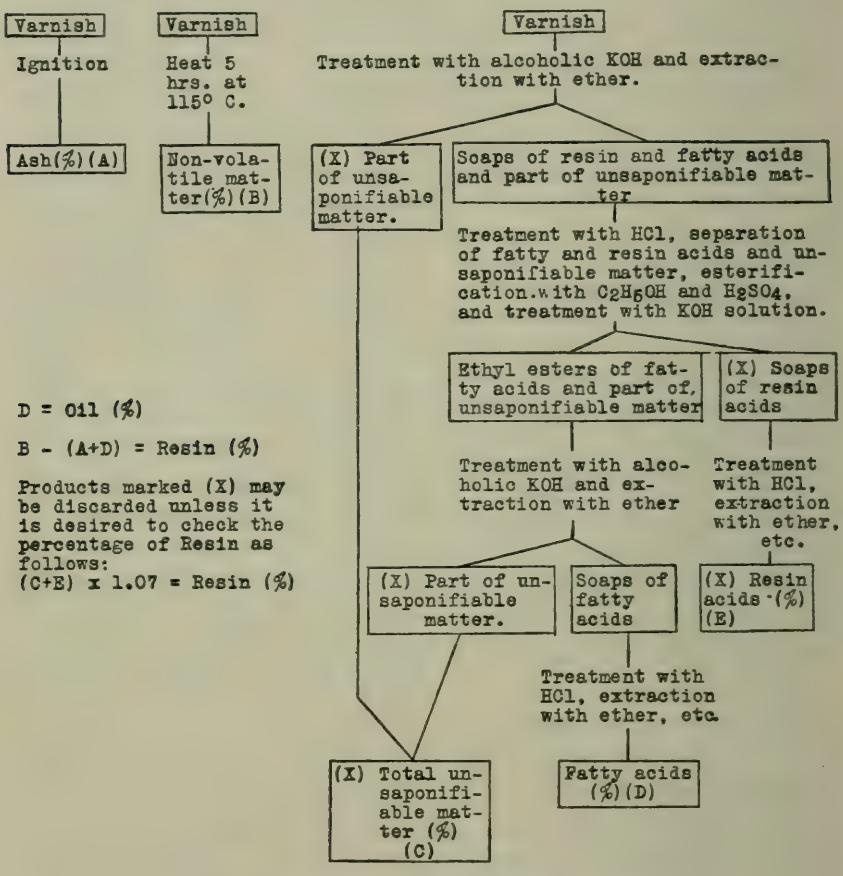
Varnish
Ignition
Ash(%)(A)
Varnish
Heat 5 hrs. at 115° C.
Non-volatile matter(%)(B)
Varnish
Treatment with alcoholic KOH and extraction with ether.
(X) Part of unsaponifiable matter.
Soaps of resin and fatty acids and part of unsaponifiable matter
Treatment with HCl, separation of fatty and resin acids and unsaponifiable matter, esterification with C_2H_5OH and H_2SO_4, and treatment with KOH solution.
Ethyl esters of fatty acids and part of unsaponifiable matter
(X) Soaps of resin acids
Treatment with alcoholic KOH and extraction with ether
Treatment with HCl, extraction with ether, etc.
(X) Part of unsaponifiable matter.
Soaps of fatty acids
(X) Resin acids (%) (E)
Treatment with HCl, extraction with ether, etc.
(X) Total unsaponifiable matter (%) (C)
Fatty acids (%) (D)
D = Oil (%)
B - (A+D) = Resin (%)
Products marked (X) may be discarded unless it is desired to check the percentage of Resin as follows:
(C+E) x 1.07 = Resin (%)

FIG. 1.—*Diagram of proposed method*

on the percentage of resin obtained by difference is desired.) Unite the solution and washings containing the soaps of the fatty acids. Add an excess of hydrochloric acid and extract twice with ether. After washing the combined ether solution with water, transfer it to a tared flask, distil off the ether, dry the residue to constant weight at 110° C, and weigh as "fatty acids." If the

determination of resin is desired, to the combined aqueous solution and washings (containing the resin soaps) add an excess of hydrochloric acid, extract twice with ether, wash the combined ether solutions twice with water, and then distil off the ether. Dry the residue to constant weight at 110° C and weigh as "resin acids." The Twitchell method of esterification may be substituted for the Wolff method.

Calculation: Report the percentage of fatty acids obtained as percentage of oil and calculate the percentage of resin by difference. Multiply the sum of the unsaponifiable matter and resin acids by 1.07 to obtain a check result for the percentage of resin. (The error introduced by omitting to correct for the percentage of unsaponifiable matter in the oil is so small that it may be ignored.) Alternative method of calculation in the absence of rosin: Multiply the percentage of fatty acids obtained by 1.06 and subtract the product from the percentage of ash-free nonvolatile matter. Multiply the result by 1.07 to obtain the percentage of resin. Calculate the percentage of oil by difference.

VI. SUMMARY

(1) The glycerol yields of varnishes, determined after saponification with aqueous potassium hydroxide solution, when multiplied by 10, gave figures which were fairly close to the amounts of oil present, except with a varnish containing Chinese wood oil, in which case the results were low.

(2) When varnishes, or the portions of varnishes soluble in petroleum ether, or the mixtures of unsaponifiable matter, fatty acids, and resin acids (separated from varnishes), were oxidized by heating thin films for eight days at 100–110° C, subsequent extraction with chloroform removed only a portion of the resinous matter present, except with a sample the nonvolatile portion of which was mainly rosin. Thus, erroneous results were obtained by the methods of Voorhees and of Livache and McIntosh.

(3) When varnishes were treated with an excess of petroleum ether, as in Voorhees's method, the precipitates obtained consisted principally of resinous matter, but contained some oil. The presence of Chinese wood oil raised the oil content of the precipitate.

(4) When varnishes were saponified, treated with acid, and the resulting mixture of unsaponifiable matter, fatty acids, and resin acids were treated with an excess of petroleum ether, as in McIlhiney's method, the precipitates obtained contained a portion of the resin present in the varnish and a small amount of fatty acids.

(5) When varnishes were extracted with petroleum ether and the petroleum ether solution was subsequently cooled, as in Darner's method, the yields of total insoluble matter were less than the amounts of resin present in the samples.

(6) As methods for the determination of total oil and resin, McIlhiney's method (when treatment of the precipitate with 85 per cent alcohol was omitted) and Darner's method gave results with a short oil varnish which were fairly accurate, but both methods with long oil varnish gave high results for total resin content and low results for oil content.

(7) The proposed method for the determination of oil and resin, involving esterification by the Twitchell or Wolff methods, the use of ether as solvent after esterification and correction of the figures by appropriate factors, gave results which were sufficiently accurate for practical purposes, and appears to be the best method so far devised for general use.

WASHINGTON, September 14, 1915.

DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

S. W. STRATTON, Director

TECHNOLOGIC PAPERS OF THE BUREAU OF STANDARDS, NO. 66

[Issued January 15, 1916]

DETECTION OF RESIN IN DRIER

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I. INTRODUCTION

In the preparation of paint by the painter a drier is added to hasten the drying. Common practice is to add about 5 parts by volume to 95 parts of oil. Commercial driers show on analysis from 2 to 10 per cent of ash, containing lead, manganese, and sometimes calcium, and from 60 to 95 per cent of volatile thinner, usually consisting of turpentine, mineral spirits,[1] or a mixture of the two. In addition to the above, what is known as "oil drier" contains linseed oil but no resin, while "japan drier" contains both linseed oil and resin.[2] This distinction, however, is not

[1] The term "mineral spirits" is being generally accepted for the petroleum distillates that are used as substitutes for turpentine.

[2] In the paint trade the resins, other than rosin, are called "gums."

strictly adhered to in the paint trade. Sometimes oil driers and japan driers are sold under other names, and there are also on the market many special and patent driers which are not used for general painting work. The resin is added to the drier to prevent precipitation of metallic soaps after thinning and to decrease the tendency of the drier to "curdle" with oil. Oil driers are made, however, containing as much as 95 per cent of mineral spirits, which contain sufficient lead and manganese to show satisfactory drying properties in laboratory tests.

The usual laboratory examination of driers includes the determination of the amount and nature of the volatile thinner, the amount and nature of the ash, a qualitative test for rosin, and drying tests with linseed oil. Purchasers of oil driers presumably desire material that is free from resins, and therefore a method for the detection of resin is needed.

II. THE SIGNIFICANCE OF RESIN IN DRIER

The following statement appears in "One Thousand More Paint Questions Answered": [3]

> Japan driers differ from oil driers in so far as the first named are composed of gums or resins fused with linseed oil and driers such as litharge, red lead, and manganese salts. * * * Oil driers are, or should be, used for oil paints for exterior work, because, being free from resinous substances, they tend less to the cracking of paint than the excessive use of japan driers, while on the other hand, the latter should be employed where quick drying, as in flat or semiflat paints, is an absolute necessity and where surfaces are not exposed to severe weather conditions.

This statement probably expresses the ideas of those who prefer oil drier. The condemnation of "the excessive use of japan driers" is undoubtedly justified, but it is highly improbable that the small amount of resin introduced into a paint by the addition of 5 per cent of japan drier would have any bad effect for outside paints. On the contrary, Dubois [4] showed that the addition of small amounts of "kauri mixing varnish" to linseed oil produced a vehicle that was superior to pure linseed oil for paints for iron and steel, the films being less pervious to water vapor and other gases. Toch,[5] in a summary of the results of exposure tests of

[3] Published by The Painters' Magazine, New York (1908).
[4] J. Ind. Eng. Chem., 5, p. 968 (1913).
[5] J. Ind. Eng. Chem., 7, p. 510 (1915).

painted steel plates on which different vehicles were used, includes spar varnish and a mixture of spar varnish and "stand" oil [6] in the class which showed "a high degree of protection against corrosion." The general use of spar varnish for exterior work on metal and wood and the practice of adding spar varnish to paint vehicles indicates that the presence of resin, when the amount is not excessive, is beneficial.

In answer to an inquiry from the Bureau of Standards, several manufacturers of driers gave their opinions regarding the classification and relative values of oil drier and japan drier. All stated that while the distinction between the two as given above is technically correct it is very frequently disregarded, and that while the amount of oil drier that is made and sold is considerable it is small in comparison with the amount of japan drier that is used. Only one manufacturer claimed that oil drier is preferable to japan drier, his statement being as follows: "Except for certain purposes a high-grade oil drier is to be preferred to a kauri japan drier." The same manufacturer stated that if rosin is present in a drier, the amount should be limited. With this exception, no manufacturer stated that the presence of rosin or mineral oil has any bad effect. One manufacturer called attention to the fact that driers (called by him "resinate driers") are used, the nonvolatile organic portion of which is composed entirely of resin.

Ordinarily the judicious use of japan drier will introduce from 1 to 2 per cent of resin into a paint and there appears to be no proof or general agreement among paint technologists that this small amount has any bad effect. It is improbable that its presence or absence makes any noticeable difference in painting results.

Although very good spar varnishes are made which contain small amounts of rosin, the presence of a large amount in a paint vehicle makes the latter unsuitable for outside work, and since no data are available to show the maximum amount which may be present without lowering the quality, specifications for driers and for outside varnishes almost always prohibit the use of rosin.

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[6] Linseed oil, heated and allowed to stand in tanks for three to four weeks.

III. EXPERIMENTAL

1. PREPARATION AND COLLECTION OF SAMPLES

The composition of the driers used in this investigation is shown in Table 1. The sample designated as No. 1 was prepared from linseed oil, litharge, manganese dioxide, and turpentine; No. 2 from these materials and kauri. Nos. 3, 4, and 5 were prepared from linseed oil, litharge, and manganese dioxide, no thinner being added. After all the oxides had been added to the heated oil, the mixtures were heated at 250–300° C for one-half, one, and two hours, respectively. Nos. 6, 7, and 8 were made in the same way as were Nos. 3, 4, and 5, except that red lead was substituted for litharge and the samples were thinned with turpentine. Seven more samples, Nos. 9 to 15, inclusive, were prepared from various resins and oils, manganese dioxide, litharge, and turpentine, the mixtures of oil, resin, and oxides being heated for one hour at 250–300° C. Nos. 16 to 39, inclusive, were obtained from manufacturers [7], the data regarding the composition of these samples being compiled from the statements of the makers. In the preparation of commercial driers, the mixtures of oil, resin, and metallic compounds are heated for so long a time and at so high a temperature that the percentages of oil and of resin in the finished driers can be only approximately estimated.

2. PRELIMINARY EXPERIMENTS

Rosin can be detected, of course, by the well-known Liebermann and Storch test with acetic anhydride and sulphuric acid. Attempts to identify and detect other resins by the color test of Hicks [8] were not successful. Determination of the acid number of the mixtures of unsaponifiable matter, fatty acids, and resin acids, obtained from the driers by saponification and subsequent treatment with acid, was found to be useless as a means for the detection of resin, because prolonged heating during the preparation of oil drier lowered the acid number very much. For

[7] For samples and information the author is indebted to the following: John Lucas & Co. (Inc.); W. P. Fuller & Co.; Samuel H. French & Co.; Pitcairn Varnish Co.; Pratt & Lambert; Sherwin-Williams Co.; and the O'Brien Varnish Co.

[8] J. Ind. Eng. Chem., 3, p. 86 (1911).

instance, the mixtures of unsaponifiable matter and fatty acids obtained from Nos. 3 and 5 (heated for one-half and two hours, respectively) showed acid numbers of 186 and 165, respectively.

3. DETECTION OF RESIN BY THE ALCOHOL METHOD

The mixtures of unsaponifiable matter, resin acids, and fatty acids, obtained from the driers as stated above, were treated with ethyl alcohol of two strengths, 95 and 97 per cent by volume. In most cases the samples containing resins other than rosin showed a marked turbidity or a deposit of insoluble matter. It will be noted from the results of these tests, as shown in Table 1, that to obtain clear solutions with Nos. 6 to 8, inclusive, it was necessary to use 97 per cent alcohol. With these samples the use of 96 per cent alcohol gave solutions that were very faintly turbid. It will be noted also that by this method it was impossible to detect the presence of rosin, manila, shellac, and the very small amounts of kauri that were present in Nos. 34 to 36, inclusive.

4. DETECTION OF RESIN BY ESTERIFICATION AND SUBSEQUENT DETERMINATION OF THE ACID NUMBER

The usual method for the determination of oil and resin in mixtures of the two includes esterification by Twitchell's [9] method, using absolute alcohol and dry hydrochloric-acid gas, or by Wolff's [10] method, using absolute alcohol and concentrated sulphuric acid. Preliminary experiments with fatty acids prepared from linseed oil, the results of which are shown in Table 2, showed that more nearly complete esterification was obtained by the former method, absolute ethyl alcohol being used. As is also shown in Table 2, variation of from two to five minutes in the time of heating in the Wolff method did not affect the results obtained with the mixtures of acids and unsaponifiable matter from oil drier and japan drier. The Wolff method is shorter and simpler than the Twitchell method, and the results obtained with various samples of driers, as given in Table 3, show that as a qualitative test for resin the former is satisfactory. The maximum figure for acid number after esterification was 9 for oil driers and the minimum figure for japan driers was 11. Since the figure obtained with

[9] J. Soc. Chem. Ind., **10**, p. 804 (1891). [10] Chem. Ztg., **38**, pp. 369–370, 382–383, 430 (1914).

No. 34 is within experimental error of the maximum figure for oil drier, the method can not be depended upon to detect less than 6 per cent of resin in the ash-free nonvolatile portion of a drier. This is ordinarily equivalent to a resin content of less than 3 per cent in a thinned drier ready for use. The figures obtained with driers are given as whole numbers because the end point of the titration, using phenolphthalein as indicator, was so obscured as to cause a possible error of 0.1 cc of 0.25 N alkali. This would result in an error of 1.4 in the acid number determined with a 1 g sample. In fact, an accuracy of two in the determination of acid number is all that can be expected. Samples that weigh over 1 g can not be used since the solutions would then be too dark in color.

TABLE 1

Detection of Resin by Alcohol Method

No.	Constituents other than thinner and metallic oxides		Name of drier given by manufacturer	Appearance of alcohol solution	
	Per cent of oil	Per cent of resin		95 per cent alcohol	97 per cent alcohol
1	Linseed, 48	None		Clear	
2	Linseed, 38	Kauri, 8		Turbid	Turbid.
3	Linseed, 85	None		Clear	
4	do	do		do	
5	do	do		do	
6	Linseed, 45	do		Turbid	Clear.
7	Linseed, 47	do		do	Do.
8	Linseed, 48	do		do	Do.
9	Linseed, 25; Chinese wood, 12	do		Clear	
10	Linseed, 26	Kauri, 6		Turbid	Turbid.
11	do	Manila, 5		Clear	Clear.
12	Linseed, 28	Manila, 8		do	Do.
13	Linseed, 30	Dammar, 6		Turbid	Turbid.
14	Linseed, 27	Rosin, 7		Clear	
15	Linseed, 25	Shellac, 5		do	
16	Linseed	Rosin	Japan	do	
17	do	None	Oil	do	
18	do	do	do	do	
19	do	"Copal gum"	Gum	Turbid	Do.
20	do	Rosin	Resin	Clear	
21	Linseed, 50	None	Specification	do	
22	Linseed, 12	Kauri, 10		Turbid	Do.
23	Linseed, 27	Rosin, 7	High-grade commercial.	Clear	
24	Linseed	"Vegetable gum."	Coach painters' japan.	Turbid	Do.

TABLE 1—Continued

Detection of Resin by Alcohol Method—Continued

No.	Constituents other than thinner and metallic oxides		Name of drier given by manufacturer	Appearance of alcohol solution	
	Per cent of oil	Per cent of resin		95 per cent alcohol	97 per cent alcohol
25	Linseed	None	Standard japan	Clear	
26	Linseed, 18	"Fossil gum," 14.	Japan	Turbid	Slightly turbid.
27	Linseed, 22	None	Oil	Clear	
28	Linseed	do	do	do	
29	do	Kauri	Japan	Turbid	Turbid.
30	do	Kauri, Rosin	do	do	Do.
31	do	Rosin	do	Clear	
32	do	do	do	do	
33	do	do	do	do	
34	Linseed, 25	Kauri dust, 1½.	do	do	
35	Linseed, 28	Kauri dust, 1	do	do	
36	Linseed, 26	Kauri dust, 1½.	do	do	
37	None	Rosin	Resinate	do	
38	Linseed	None	Linoleate	do	
39	do	do	do	do	

TABLE 2

Results with Twitchell and Wolff Methods of Esterification

Material	Method	Time of heating	Acid number (mg. of KOH per gram of acids + unsaponifiable matter)
		Minutes	
Fatty acids + unsaponifiable matter from raw linseed oil	Twitchell		2.7 3.3
Average			3.0
Fatty acids + unsaponifiable matter from raw linseed oil	Wolff	2	6.6 5.7
Average			6.2
Fatty acids + unsaponifiable matter from oil drier, No. 8	Wolff	2 3 5	8 8 7
Fatty acids + resin acids + unsaponifiable matter from japan drier, No. 12	Wolff	2 3 5	19 18 19

TABLE 3

Results with Driers, using Wolff Method of Esterification

Sample	Acid Number	Average.
Oil drier No. 6; linseed oil, 45 per cent	9 7	8
Oil drier No. 7; linseed oil, 47 per cent	8 8	8
Oil drier No. 8; linseed oil, 48 per cent	7 7	7
Oil drier No. 8a [a]	9 7	8
Oil drier No. 27; linseed oil, 22 per cent	9 8	8½
Japan drier No. 10 {linseed oil, 26 per cent kauri, 6 per cent	13 13	13
Japan drier No. 11 {linseed oil, 26 per cent manila, 5 per cent	14 16	15
Japan drier No. 12 {linseed oil, 28 per cent manila, 8 per cent	19 18	18½
Japan drier No. 15 {linseed oil, 25 per cent shellac, 5 per cent	16 16	16
Japan drier No. 34 {linseed oil, 25 per cent kauri dust, 1½ per cent	11 11	11
Japan drier No. 35 {linseed oil, 28 per cent kauri dust, 1 per cent	13 15	14
Japan drier No. 36 {linseed oil, 26 per cent kauri dust, 1½ per cent	12 14	13

[a] No. 8 without thinner.

IV. PROPOSED METHOD FOR THE DETECTION OF RESIN IN DRIERS

(1) Test for rosin by the Liebermann and Storch method with acetic anhydride and sulphuric acid.

(2) If no rosin is detected by (1), place about 25 cc of the drier in a flask and pass in a rapid current of steam while heating the flask in an oil bath at 130° C. Add an excess of alcoholic potash, and heat on the steam bath for one hour. Add an excess of hydrochloric acid and shake vigorously. Fill the flask with hot water and allow the oily layer to collect in the neck of the flask. Remove about 5 cc of this oily layer to another flask, add about 25 cc of dilute hydrochloric acid (1:1), and boil for a few minutes. This is necessary to insure the decomposition of all metallic soaps.

Cool, add about 20 cc of ether and sufficient water to bring the ether solution into the neck of the flask. Filter a portion of this ether solution into a flask, evaporate off the ether, and dry the residue at 110–115° C for one-half hour. Place 0.15–0.20 g of this residue in a test tube, add 5 cc of ethyl alcohol (97 per cent by volume), and shake. A turbidity or a deposit of insoluble matter shows the presence of resin in the sample.

(3) If no resin is detected by (1) or (2), filter into a tared flask a sufficient amount of the ether solution obtained in (2) to yield a dry residue of 0.8–1.0 g. Evaporate and dry as stated under (2) and weigh the flask and dried residue. Add 10 cc of absolute ethyl alcohol, warm gently till the solution is clear, and add a mixture of 10 cc of absolute ethyl alcohol and 3 cc of concentrated sulphuric acid. Boil under a reflux condenser for two or three minutes, cool, and transfer the contents of the flask to a separatory funnel, washing out the flask with water and ether. Add 25 cc of a 10 per cent solution of sodium chloride and shake. Draw off the lower layer and shake it with 50 cc of ether. Unite the ether solutions and wash with water until the washings are neutral. Three washings will usually suffice. Transfer the ether solution to a large flask and dilute with neutral 95 per cent alcohol until the color of the solution is sufficiently light to permit of titration with 0.25 N alcoholic potash, using phenolphthalein as indicator. Dilution to 400–600 cc is generally necessary. If the dilution with alcohol causes a turbidity, add sufficient ether to clear the solution. Titrate with 0.25 N alcoholic KOH and calculate the acid number as milligrams of KOH per gram of the mixture of unsaponifiable matter and acids taken. An acid number of over 10 shows the presence of resin in the sample.

V. SUMMARY

A method has been developed for the detection of resin in driers which is reliable except when the resin content is very small, e. g., less than 6 per cent of the ash-free nonvolatile portion.

WASHINGTON, November 2, 1915.

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DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

S. W. STRATTON, Director

TECHNOLOGIC PAPERS OF THE BUREAU OF STANDARDS, No. 67

[Issued January 31, 1916.]

SOME QUALITATIVE TESTS FOR GUM ARABIC AND ITS QUANTITATIVE DETERMINATION

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I. INTRODUCTION

The group of polysaccharides includes such diverse substances as the starches, cellulose, the dextrins, the true gums, and the plant mucilages. They possess in common the property of being decomposable hydrolytically into one or more sugars, usually pentoses or hexoses. By oxidation, the acids corresponding to

these sugars are formed, but the first step toward this reaction appears to be hydrolysis.

The true gums, of which gum arabic is typical, dissolve in cold water, yielding clear solutions which, though viscous and adhesive, can be filtered. The closely related and quite similar mucilages, such as gum tragacanth and cherry-tree gum, simply swell up and form more or less homogeneous suspensions that can not be filtered. Perhaps most of the so-called gums are mixtures of one or more representatives of each of the above two classes.

As might be expected from their chemical nature, the gums do not readily lend themselves to reactions of a definite qualitative or quantitative value. One of us learned how unsatisfactory some of the qualitative tests are when samples of mucilage first came to the Bureau of Standards for examination. This led to an extended study of the literature and of the various qualitative reactions that have been published, and finally to a comparatively accurate quantitative method. In the last part of this work the two of us joined forces, hoping to carry on a much more extended investigation than was found later to be possible.

The object of this paper is to bring together all the more important qualitative and quantitative methods that have been published and to present a new procedure for the determination of gum arabic. Since in most cases it is necessary to know only whether gum arabic is present or not, it is believed that the following summary and criticism of the qualitative tests will be of value. Many of the quantitative methods depend on the same reactions.

II. QUALITATIVE TESTS

In nearly all cases a 2 per cent solution of gum arabic was used. Similar solutions of dextrin and of gum ghatti, a substitute for gum arabic, were subjected to the same tests.

1. Ferric Chloride and Alcohol.—A solution of ferric chloride, made up without the addition of hydrochloric acid and filtered to remove a small amount of basic salt, was used. It contained about 25 g of the salt in 100 cc. Neither gum arabic, gum ghatti, nor dextrin gave a precipitate with this reagent.

A mixture of 2½ volumes of 50 per cent alcohol and the ferric-chloride solution precipitates gum arabic, though often only on

long standing.[1] Gum ghatti gives no precipitate, and dextrin a very slight one.

2. Potassium Hydroxide.—According to Liebermann,[2] solutions of gum arabic and of dextrin become amber-yellow when warmed with potassium hydroxide, while the closely related gum senegal gives at most a faint yellow color. Sollman [3] stated that dextrin, when so treated, turns more or less brown, while some sugars and gums, other than arabic, behave similarly. Rideal and Youle [4] came to the conclusion that this test is of no value. Two samples of gum arabic, among a number tested by them, gave a green color. They found that a solution of ghatti turns pink and dextrin a very dark red or almost black. Nevertheless, this test is among those recommended in the latest edition of Lunge.[5]

Our experiments with gums and sugars amply confirmed the statement that this test is of no value.

3. Color Reactions with Phenols.—Reiche [6] found that gum arabic gave a flocculent blue precipitate when boiled with orcinol and concentrated hydrochloric acid. Other carbohydrates, including dextrin, cellulose, sugars, starch, and a number of gums, gave yellow or brown colors.

Ihl [7] was able to distinguish between gum arabic, dextrin, and starch by means of α- and β-naphthol and phloroglucinol. With resorcinol and pyrogallol, all three carbohydrates gave the same color.

In this connection may be mentioned a curious reaction discovered by Clermont and Chautard.[8] A solution of pyrogallol, containing gum arabic, gave a yield of 67 per cent of the condensation product, purpurogallin (pyrogalloquinone), on standing for two months.

In the hope of obtaining definite color reactions, hydrochloric acid-alcoholic solutions of the following phenols were made up: Phenol, resorcinol, pyrocatechol, guaiacol, hydroquinol, pyrogal-

[1] Roussin: J. Pharm. Chim., [4], **7**, p. 251; 1868. See also Allen, Coml. Org. Anal., 4th ed., **3**, p. 443.
[2] Chem.-Ztg., **14**, p. 665; 1890.
[3] Am. J. Pharm., **83**, p. 176; Chem. Zentr., **82**, 1, p. 1560; 1911.
[4] J. Soc. Chem. Ind., **10**, p. 610; 1891.
[5] Chem.-Techn. Untersuchungsmeth., 6th ed., **3**, pp. 167–168; 1911.
[6] Ber. Ges. Förder. chem. Ind., 1879, p. 74; Chem.-Ztg., **4**, p. 191; 1880.
[7] Chem.-Ztg., **9**, p. 231; 1885.
[8] Compt. Rend., **94**, p. 1254; Jahresber., 1882, p. 684.

lol, phloroglucinol, and α- and β-naphthol. These were heated, in test tubes set in beakers of water on the steam bath, with dextrin and gums arabic, ghatti, and tragacanth. A considerable range of colors resulted: Pale yellow, pale pink, red-brown, brown, pale orange, purple-red, etc., but no reliance could be placed in any of the reactions as a means of identification.

Some interesting results were obtained by heating the same carbohydrates with alcohol and hydrochloric acid, without the addition of a phenol. Dextrin gave no color, gum arabic a pale yellow, and tragacanth a pale pinkish-yellow. A sample of gum ghatti, prepared by powdering together a number of lumps taken at random, gave a pale-yellow solution with perhaps a tinge of pink. The addition of a clear lump of the gum caused no change, while a dark, impure piece produced a dark pink. There may be some connection between these color reactions and the behavior of different lumps of ghatti toward the guaiacol-hydrogen peroxide reagent, which is discussed further on.

4. Basic Lead Acetate.—An aqueous solution of neutral lead acetate precipitates neither dextrin nor gums arabic and ghatti. An alcoholic solution of the salt does, however, slowly precipitate gum arabic.[9]

As might be expected from its employment in clarifying sugar solutions before polarization, basic lead acetate is an excellent precipitant for many gums. The solution may be made basic either by adding ammonia,[10] or by boiling with litharge. The precipitate formed when gum-arabic solution is added is of a peculiar curdy consistency, and of such characteristic appearance that it is hardly necessary to make any confirmatory tests.

Allen [11] speaks of this precipitate as a "white jelly." Dextrin solutions are, at most, made slightly cloudy by the reagent, while gum ghatti yields a very small amount of precipitate, most of which remains suspended in the liquid.

The basic acetate solution used by us was made by long-continued boiling of 40 g of crystallized lead acetate, dissolved in 250 cc of water, with an excess of litharge. It was filtered, after which it remained clear for a long time.

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[9] Chauvin: Mon. Sci., [5], 1, pp. 317-8; 1911; Chem. Zentr., 82, 1, p. 1656; 1911.
[10] v. Lippmann: Chemie der Zuckerarten, III Aufl., p. 1616.
[11] Loc. cit.

Basic lead acetate has been recommended probably more frequently than any other reagent as a qualitative test for gum arabic, as well as for removing this and other gums from wines, liqueurs, etc., in which other constituents are to be determined.[12]

5. Copper Sulphate and Sodium Hydroxide.—Jettel [13] does not mention the basic lead acetate test, but relies chiefly upon the behavior of dextrin, gum arabic, etc., toward copper sulphate and sodium hydroxide. The test was devised by Liebermann [14] for detecting dextrin and gum senegal in the presence of gum arabic. The precipitate formed in a solution of gum arabic by adding copper sulphate and then an excess of sodium hydroxide, balls together and rises to the top. That from senegal is less in amount and is in finer particles that remain distributed throughout the liquid. On warming, these precipitates dissolve to only a slight extent, and even on boiling there is no reduction to cuprous oxide. A solution of dextrin yields a precipitate that dissolves on warming. The cupric salt contained in the dark-blue liquid is completely reduced by boiling.

To these statements of Liebermann we may add that gum ghatti gives a dark-blue solution which is, at times, slightly turbid, but clears up on warming gently. There is slight reduction on boiling, but this may not be noticed unless a long time is allowed for the cuprous oxide to settle.

In the second part of this paper is described a quantitative method for gum arabic, based on a modification of Liebermann's reagent.

6. Miscellaneous Qualitative Tests.—Many other reagents for gum arabic have been suggested from time to time, but most of them deserve only brief mention.

One of the most interesting of these depends on the presence of an oxidase in gum arabic, and was devised for the detection of this gum when mixed with tragacanth, in which there is no such

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[12] Rideal and Youle: J. Soc. Chem. Ind., **10**, p. 610; 1891.
Fromm: Z. anal. Chem., **40**, p. 143; 1901.
Papasogli: L'Orosi, **21**, pp. 263–265; 1898.
Scheibler: Z. Ver. d. Zuckerind., **23**, p. 288.
Battut: Sucr. Indig. et Colon., **32**, p. 285.
v. Lippmann: Chemie der Zuckerarten, p. 1616.
Allen: Coml. Org. Anal., 4th ed., **1**, pp. 440 et seq.

[13] "Zündwaren" in Lunge: Chem.-Techn. Untersuchungsmeth., 6th ed., **3**, pp. 167–168.

[14] Chem.-Ztg., **14**, p. 665; 1890.

enzyme.[15] To a suspension of the powdered gum in 30 parts of cold water is added an equal volume of a 1 per cent aqueous solution of guaiacol, followed by a drop of hydrogen peroxide. If gum arabic is present, the mixture at once turns brown. Dextrin, of course, does not react. Gum ghatti may not react, even after standing for half an hour. With some pieces, however, the color is produced. This recalls the behavior of the gum toward a mixture of alcohol and hydrochloric acid. (See under 3, above.)

Bornträger[16] suggested warming a suspected sample with 50 per cent hydrofluoric acid. When much bone glue is present, the odor of butyric acid is noticed. Dextrin is detected by its own characteristic odor, while with gum arabic only that of hydrofluoric acid is noticed.

According to Petri,[17] aliphatic aldehydes, certain sugars, and gum arabic give a fuchsin-red color when mixed with alkali and diazobenzenesulphonic acid. The color is gradually developed.

Günsberg[18] used a fresh solution of egg albumen, acidified with acetic or hydrochloric acid, as a reagent for gum arabic. Dextrin yields a dense precipitate which is insoluble in an excess of acid or of dextrin solution. With gum arabic only a little must be added, for the precipitate first thrown out dissolves in even a slight excess. Any albumen that is not precipitated by the gum arabic can be coagulated by heat, although under ordinary circumstances acidified albumen is not coagulable.

Vamvakas[19] found that as little as 5 per cent of gelatin can be detected in gum-arabic mucilage by means of Nessler's reagent. The mucilage is shaken with one-fourth its volume of the reagent and allowed to stand. If no gelatin is present, the brownish-gray precipitate remains suspended for some days. With an admixture of gelatin the precipitate is dull gray and settles more rapidly. In the presence of tartaric acid even a 30 per cent solution of gum arabic yields but a slight precipitate with Nessler's reagent.

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[15] Payet: Apoth. Ztg., **25**, p. 116; Z. anal. Chem., **44**, p. 453; 1905.
[16] Oesterr. Chem. Ztg., **3**, p. 1888; Z. anal. Chem., **40**, p. 131; 1901.
[17] Z. physiol. Chem., **8**, p. 291; Jahresber., 1884, p. 1328.
[18] J. prakt. Chem., **88**, p. 239; Z. anal. Chem., **2**, p. 218; 1863.
[19] Ann. Chim. Anal. Appl., **12**, pp. 12 and 139; 1907. Analyst, **32**, pp. 93 and 226; 1907.

These reactions call to mind the mixture of mercuric acetate and sodium chloride suggested by Hager.[20] When warmed with glucose there is no change, while gum arabic, dextrin, and cane sugar reduce the mercuric salt with formation of calomel.

In this connection also should be mentioned the reduction of molybdic acid when boiled with a solution of dextrin.[21] A blue solution results, while with gum arabic there is no change.

Analogous to the reaction with copper sulphate and alkali is the formation of a stable blue color when a solution of gum arabic or of dextrin is mixed with cobalt-nitrate solution, followed by dilute sodium hydroxide.[22]

Zsigmondy,[23] using a deep red solution of colloidal gold as a reagent for colloids, studied the color changes produced by glue, gums, albumen, etc.

Other reagents for gum arabic, such as sodium or potassium silicate, borax, or ammonium oxalate,[24] would seem to depend largely upon the natural calcium content of the gum, though some of the reagents are said to produce gelatinization.

In our work solutions of various salts were mixed with 2 per cent solutions of gum arabic, but in no case was there precipitation or gelatinization. These salts need not be enumerated, except to say that, among others, such promising reagents as basic zinc salts and sodium zincate were found to be useless.

Gum arabic gives no color reaction with iodine solution.

7. CHIEF QUALITATIVE TESTS FOR GUMS AND DEXTRIN.—Most of the tests described above, as well as others not mentioned, were tried. Most of them were unsatisfactory. After the work had progressed far enough to show which tests are reliable we succeeded in obtaining new samples. The five or six lots already on hand were from different dealers and the original sources were not known. The new ones included gum arabic from Khartum and Kordofan, a second supply of gum ghatti, and the closely related gum gedda. It is unnecessary to discuss these in

[20] Pharm. Centralhalle, **18**, p. 313. Z. anal. Chem., **17**, p. 380; 1878.
[21] Hager: Commentar zur ersten deutschen Pharmakopöe, **II**, p. 116. Cf. Stohmann in Muspratt, 4th ed., **3**, p. 1917; 1891.
[22] Papasogli: L'Orosi, **21**, pp. 263–265; 1898. Chem. Centr., **69**, II, p. 991; 1898.
[23] Z. anal. Chem., **40**, p. 697; 1901.
[24] Allen: Loc. cit., p. 441.

detail since their reactions are included in the table below. All samples of gum arabic, from whatever source, behaved alike. Gum gedda, it will be seen, acts much like a mixture of gums arabic and ghatti. Only the tests that are most reliable are included. The gum solutions were prepared by dissolving 1 g. of the solid in 50 cc of hot water and straining through a loose plug of cotton.

TABLE 1

Chief Qualitative Tests for Gums and Dextrin

Reagent	Gum arabic	Gum ghatti	Gum gedda	Dextrin
Ferric chloride and alcohol.	Precipitate.....	Nearly clear.....	Slight precipitate....	Slightly cloudy.
Basic lead acetate....	Dense precipitate..	Cloudy.....	Less precipitate than arabic.	Slightly cloudy.
Copper sulphate and sodium hydroxide (cold).	Blue precipitate, colorless solution.	Dark-blue solution, often cloudy.	Light-blue precipitate, dark-blue solution.	Dark-blue solution.
As above, but boiled..	Precipitate darker, pale-blue solution.	Slight reduction...	Precipitate darker...	Complete reduction.
Iodine solution.....	(a)	(a)	(a)	Reddish-purple solution.

[a] No characteristic color reactions.

III. QUANTITATIVE METHODS

Since the chemical nature of the gums is such as to render most of the qualitative tests of at least doubtful value, it is not surprising that there are difficulties involved in their quantitative separation and determination. Some of the methods that have been proposed will be reviewed below, following which our own procedure will be described.

1. Ferric Chloride and Calcium Carbonate.—The first qualitative test mentioned above was the formation of a precipitate when neutral ferric-chloride solution and alcohol are added to a solution of gum arabic. This precipitate is soluble in dilute acid, so that the gum is not completely thrown down unless the acid that is simultaneously set free is neutralized. Roussin [25] found that calcium carbonate is satisfactory for the purpose. The gum solution is mixed with alcohol and ferric chloride, and

[25] Loc. cit. See also Allen; loc. cit.

an excess of the carbonate is then added. The mixture of precipitated gum and ferric hydroxide, which is rather difficult to filter, is washed with alcohol, dissolved in hydrochloric acid, the gum thrown out by strong alcohol, washed with the same reagent, dried, and weighed.

Roussin devised this method for the quantitative separation of gum arabic from dextrin. It is recommended by Allen, and was found by Auguet to give good results in determining the gum in sirups.[26]

2. FERRIC CHLORIDE AND SODIUM CARBONATE.—Another method based upon the reaction with ferric chloride was suggested by Landwehr [27] for the determination of glycogen and, incidentally, of gum arabic. Concentrated ferric-chloride solution is added in slight excess, followed by concentrated sodium carbonate until all of the iron is thrown down. The precipitate is at once filtered off, washed with hot water, dried at 110°–120°, and weighed. It is then ignited and the weight of ash deducted from that of the precipitate.

Determinations were made of the percentages of water held by ferric hydroxide when dried to constant weight at different temperatures. A correction for this water, calculated from the excess of ferric chloride, is applied to the weight of the original precipitate. It is not clear, however, just how this excess is to be determined, nor is the retention of moisture by the precipitated gum taken into account.

3. LEAD ACETATE.—As already stated, Chauvin [28] suggested the employment of an alcoholic solution of neutral lead acetate for the precipitation of gum, especially from sirups, but found that long standing was necessary. Rocques and Sellier [29] also found that this procedure gives good results.

As far as we are aware, the basic acetate has not been used for the quantitative determination of gum. Various formulas have been ascribed to the precipitate,[30] and it is not unlikely that it may vary in composition.

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[26] Ann. Falsific., **2**, pp. 136–168; Chem. Abstr., **5**, p. 538, 1911.
[27] Z. physiol. Chem., **9**, p. 164, 1884.
[28] Footnote 9; see also Ann. Falsific., **5**, pp. 27–30; Chem. Zentr., **83**, I, p. 756; 1912.
[29] Ann. Chim. Anal. Appl., **16**, pp. 218–220; 1911; Chem. Zentr., **82**, II, p. 394; 1911.
[30] Riegel: Arch. Pharm. [2], **54**, p. 155; Jahresber., **1**, p. 795; 1847–48.
Battut: Sucr. Indig. et Colon., **32**, p. 285.
Scheibler: Z. Ver. d. Zuckerind., **23**, p. 288.

4. Alcohol.—Chauvin,[31] on account of the slowness of precipitation when lead acetate is used, employed alcohol acidified with hydrochloric acid. The addition of the latter is not necessary, for the gums are all insoluble in strong alcohol. This has often been taken advantage of to remove them from wines, plant extracts, etc.[32]

5. Miscellaneous Methods.—Gum arabic can be hydrolyzed to a mixture of hexoses and pentoses by warming with dilute mineral acid, though not all samples yield these in the same proportions. Hence, quantitative methods based upon the use of Fehling's solution (hexoses), or upon the estimation of furol (pentosans) have failed.[33]

By digesting with moderately strong nitric acid, gum arabic is oxidized to mucic acid, which can be determined with fair accuracy, but samples of gum from different sources yield different percentages of the oxidation product.[34]

Williams,[35] working with quite a number of gums and resins, determined the iodine absorption number and the acidity of gum arabic, as well as the amount of alkali taken up when it is boiled with alcoholic potash. His figures showed that samples of gum differ so widely that methods involving these determinations are of no value.

6. Copper Sulphate and Alkali.—Madsen[36] estimated the gum in licorice juice (succus liquiritiae) by throwing it out with strong alcohol, dissolving in a little water, and then treating with a 10 per cent solution of copper sulphate, followed by an excess of sodium carbonate. The precipitate is probably identical with that formed by the combined action of copper sulphate and sodium hydroxide. After filtering off the precipitate, it is washed with weaker and weaker soda solution, dissolved in dilute hydrochloric acid, and the gum thrown down by 85 per cent alcohol. After washing with alcohol it is dried and weighed. The weight, multiplied by 1.21, gives the percentage of gum. This is not said to

[31] Loc. cit.
[32] Diehl: Pharm. Rundschau, 1, p. 31; Z. anal. Chem., 22, p. 622; 1883.
Madsen: Pharm. Centralhal.e, 20, p. 144; Z. anal. Chem., 22, p. 134; 1883.
[33] v. Lippmann: Loc. cit.
[34] Kiliani: Ber. d. Chem. Ges., 15, pp. 34–37; 1882.
[35] Chem. News, 58, p. 224; Z. anal. Chem., 28, p. 732; 1889.
[36] Loc. cit. See footnote 32.

be identical with gum arabic, but for botanical reasons may well be quite similar to it.

During the course of our tentative experiments, and without knowledge of the work of Madsen, an attempt was made to precipitate gum arabic by means of copper sulphate (5 g of the crystallized salt in 100 cc of water) and sodium carbonate (13.25 g of the anhydrous salt in 100 cc of alcohol of the maximum strength that would give a clear solution). Whether the soda was added before or after the copper solution made no difference in the result. The filtrate was always cloudy, even though the precipitate was so gelatinous that filtration was very slow.

Promising, though still too low, results were obtained with 10 per cent sodium hydroxide, instead of soda, followed by the addition of enough absolute alcohol to bring the total up to about 60 per cent strength. The precipitate was washed with alcohol, dried, weighed, and ignited. After deducting the weight of the ash, the percentages of gum found in four determinations varied from 84.6 to 90.1. In each of these four determinations the weight of ash from the copper precipitate was a little greater than that of the gum taken, owing to the fact that there was a considerable excess of copper in the form of hydroxide. Since this increased the time required for drying, besides being otherwise objectionable, some qualitative tests were made with a modified Fehling solution, with the hope that these difficulties would be avoided. Twenty cubic centimeters of copper-sulphate solution and 15 cc of sodium-hydroxide solution, of the strengths stated above, were mixed, enough Rochelle salt was added to dissolve the precipitate, and the whole diluted to 100 cc. To a solution of about 0.25 g of gum in 40 cc of water there was added 50 cc of the Fehling solution, but with no apparent change, except at times a slight cloudiness. While stirring vigorously, 90 cc of 95 per cent alcohol was then added, whereupon the familiar blue precipitate formed in fine particles that soon settled. Blanks showed that no cloudiness was produced in the Fehling solution when mixed with water and alcohol in the quantities stated.

The precipitate was filtered off, washed successively with 50, 75, and 95 per cent alcohol, dried at 110° to 115°, weighed, etc., as before. Two determinations, made exactly as stated, gave the

values 95.6 and 94.9 per cent of gum. When the gum was dissolved in 25, instead of 40 cc of water, the percentage found was 97.2. The original dried gum yielded 2.8 per cent of ash, chiefly calcium carbonate, with a little potassium carbonate. No correction was made for this ash in calculating the above percentages. In each of the three determinations just mentioned the weight of the ash from the copper precipitate weighed less than half as much as the gum.

Since the gum-copper precipitate is of a gummy nature, it is not possible to completely remove foreign salts by any amount of washing. Both copper sulphate and sodium sulphate are insoluble in alcohol of the strength used. This is not true of the respective acetates or of Rochelle salt, so that in another series of determinations copper acetate was employed. It is not necessary to go into details further than to say that the results were a few per cent below or above 100 with varying dilution of the gum solution and of the Fehling solution, and according to the final percentage of alcohol in the mixture.

Even this reagent was not ideal, for there must always be present the excess of copper salt, as well as the Rochelle salt and the sodium hydroxide and acetate.

7. Method Finally Adopted.—Copper acetate dissolved in ammonia possesses obvious advantages over all the other solutions employed. In order to ascertain the best conditions for precipitation, a few preliminary tests were made. One-quarter gram of gum arabic was dissolved in 50 cc of water, 25 cc of ammoniacal copper-acetate solution (see below) added, and then enough alcohol to give the required percentage of the total volume of the mixture. Thirty per cent of alcohol gave no precipitate. With 40 per cent there was a faint precipitate, so finely divided that it was practically impossible to filter. With 50, 60, and 70 per cent of alcohol, respectively, dense and easily filtered precipitates were formed. The addition of more alcohol to the filtrates from these three caused no further precipitation. These precipitates gave on ignition the following amounts of ash, practically cupric oxide.

TABLE 2

Ash Found With Varying Alcohol Content

Alcohol	50%	60%	70%
	G	G	G
Ash	0.0412	0.0436	0.0544
	.0402	.0446	.0564
	.0398	.0452	.0548
Average	.0404	.0445	.0552

From this it will be seen that in the presence of 50 per cent of alcohol the gum is precipitated quantitatively and carries down with it less occluded matter than when the mixture contains more alcohol.

The following procedure was finally adopted for the determination of gum arabic: Fifty grams of copper acetate was dissolved in water, an excess of ammonia added, and the solution diluted to 1000 cc, using water and alcohol in such proportions that the final solution contained 50 per cent of alcohol. For each determination a 50 cc portion of a gum-arabic solution, representing 0.25 g of gum, was pipetted into a 250 cc beaker, an equal volume of alcohol added, and then 25 cc of the copper reagent, with constant stirring. The precipitate was allowed to settle, was filtered on a tared paper, washed with 50 per cent alcohol containing ammonia, then with 75 per cent, and finally with 95 per cent alcohol. It was dried to constant weight at 105°, ignited in a porcelain crucible, and the ash weighed. The amount of ash was deducted from the weight of the original precipitate and the difference called "net gum arabic." The amount of moisture in the gum originally taken for analysis must be allowed for. This is determined by drying in a current of hydrogen at 105°. No allowance is made for the potassium and calcium which form an integral part of the gum. These may be to some extent retained in the precipitate and, therefore, be included in the ash. Any error that may be introduced by neglecting this is small and very much less than the error inherent in the method.

In some of the preliminary work the gum-copper precipitate was dried at 95° and then at 105°. The additional loss in weight

at the higher temperature was usually about 3 or 4 mg, or 1.5 per cent.

The following table gives the results of a number of determinations on 0.25 g portions of gum. Since this contained 11.5 per cent of moisture, the amount of actual gum was 0.2213 g. The precipitates were dried at 105°.

TABLE 3

Results Obtained By the Ammonia-Copper Acetate Method

Series	Total precipitate	Ash	Net gum	Percentage found	Average of series
	G	G	G		
A	0.2570	0.0433	0.2137	96.6	
	.2596	.0428	.2168	98.0	
	.2613	.0470	.2143	96.9	
	.2647	.0469	.2178	98.4	
	.2554	.0413	.2141	96.7	97.3
B	.2970	.0755	.2215	100.1	
	.2840	.0649	.2191	99.0	
	.2837	.0663	.2174	98.3	
	.2887	.0689	.2198	99.3	
	.3012	.0785	.2227	100.7	99.5
C	.2880	.0659	.2221	100.4	
	.2908	.0668	.2240	101.2	
	.2844	.0651	.2193	99.1	
	.2853	.0646	.2207	99.7	
	.2827	.0640	.2187	98.8	99.9
D	.2880	.0633	.2247	101.6	
	.2927	.0653	.2274	102.8	
	.2982	.0697	.2285	103.3	102.6
General average				99.5	

It is evident from an inspection of the figures that the method as finally modified is capable of yielding results as accurate as can be expected. It is realized, however, that much work could yet be done with mixtures of gum arabic with ghatti, dextrin, etc., as well as with mucilages of known composition. A few preliminary determinations, made while Fehling solution was still being experimented with, indicate that dextrin and ghatti tend to be carried down with the gum arabic. At the same time a sample of mucilage was prepared according to the formula in the United States Pharmacopoeia; from this the gum was precipitated by strong alcohol, dried, and analyzed. The net gum found in four deter-

minations was about 91 per cent. This low result may be due to a fault of the method or to partial hydrolysis of the gum.

The publication of the results thus far obtained has been so long delayed, and the opportunity to complete the work seems so remote, that it has been decided to present this paper without further postponement.

IV. SUMMARY

An incorrect report to the effect that a certain sample of mucilage contained no gum arabic led to a study of many of the published tests for this gum, as well as to a search for others than the few that proved to be reliable. It was found that basic lead acetate gives the most characteristic reaction, while mixtures of copper sulphate and sodium hydroxide, and of neutral ferric chloride and alcohol are of value as confirmatory tests.

A summary of the more important methods that have been proposed for the quantitative estimation of gum arabic is next given, followed by a description of the steps that led the authors to the use of alcoholic copper acetate-ammonia solution for this determination.

WASHINGTON, October 28, 1915.

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BUREAU OF STANDARDS

S. W. STRATTON, Director

TECHNOLOGIC PAPERS OF THE BUREAU OF STANDARDS, NO. 69

[Issued February 18, 1916]

DETERMINATION OF CARBON IN STEELS AND IRONS BY DIRECT COMBUSTION IN OXYGEN AT HIGH TEMPERATURES[1]

By J. R. Cain, Associate Chemist, and H. E. Cleaves, Assistant Chemist

The influence of temperature on the results obtained by the direct combustion of steel and iron in oxygen has been frequently investigated[2] and the general consensus of opinion seems to be that higher results for carbon are obtained with higher combustion temperatures. This conclusion, however, is rendered doubtful by a number of circumstances: (1) Quite frequently, because of uncertainties in blanks it is impossible to conclude whether the difference in results claimed is due to variation in blank or is real; (2) the published work does not indicate that investigators have always assured themselves that the material used to support the drillings or that the fluxes sometimes used are completely free from carbon; (3) differences in carbon results with the same steel are frequently due to a variation in the size of drillings used.

Combustions of steel are ordinarily made in such a way that the oxides are in the fused condition for only a very short time. This

[1] This paper is an amplification of a preliminary paper on this subject by the same authors. See J. Wash. Acad. Sci., 4, p. 393; 1914.

[2] See Lorenz, Z. Angw. Chem., 6, pp. 313, 395, 411, 635; and Foerster, Z. Anorg. Chem., 8, p. 274, 1895, for work at high temperatures; for references to work at other temperatures, see article by Mueller and Diethelm, Z. Angw. Chem., 27, p. 2114; 1910.

is evident from work done here, which shows that the fusion point of the oxides themselves is above 1450°,[3] and that as soon as the fused material has combined with or permeated the bed material the melting point of the combination becomes much higher. The temperature of a combustion furnace as ordinarily operated does not exceed 1200° and usually lies between 950° and 1100°, hence it is evident that the oxides from 1 or 2 grams of steel must solidify very rapidly after the combustion period is over, for it is only during this time that the temperature is above the melting point of the oxides. Burning in the ordinary way, if the sample consists of very large particles there is always the danger of incomplete combustion of all its parts; on the other hand, if the particles are very small the combustion may proceed so rapidly as to cause initial fusion of a portion of the oxides followed by quick solidification of the fused part with resultant inclosure of yet unburned metal. There is some chance, too, that carbon dioxide or monoxide may be inclosed in the solidified mass, and that with certain alloy steels difficult oxidizable carbides (silicon, tungsten, chromium) may escape oxidation except at very high temperatures.

A consideration of these facts, together with previous experimental work here and elsewhere, which showed that oxides from apparently well-burned samples yielded additional carbon upon being finely pulverized and reburned, led to the development of the present method, in which the sources of error cited in the first paragraph are eliminated. The object of this work was to develop a procedure which would give the best possible chance for oxidation and liberation of all the carbon in the sample, regardless of the original size of drillings, and especially to ascertain by such method the order of the error, if any, which affected the carbon determinations reported on the certificates for the Bureau's series of standard analyzed irons and steels. The latter determinations were made as usual either by direct combustion of the metal at temperatures of 950° to 1200°, or else by burning the carbon residue left after solution of the steel or iron in a suitable solvent.[4] Briefly, our method consisted in burning the metal directly in oxygen within the usual tempera-

[3] By G. K. Burgess and R. G. Waltenburg, unpublished.

[4] In a few cases certificate results include the carbon obtained from reburning the oxides.

ture range, then raising the temperature to a point above the fusion point of the oxides and maintaining this temperature long enough to insure that all parts of the sample had been brought in contact with oxygen or fused iron oxide. The sample was burned directly on platinum (with precautions described later), so that no carbon could be obtained from the support for the drillings; the carbon was estimated by the barium carbonate titration method devised by one of the authors [5] and in such way that the blank was negligible.

It seemed first desirable to know whether carbon dioxide or monoxide were left inclosed in the oxides produced during the direct combustion process as ordinarily carried out. To determine this there was used an apparatus consisting of an evolution flask connected to a suitable purifying train followed by absorption tubes for carbon dioxide and monoxide.[6] In the evolution flask there was placed a large excess of concentrated hydrochloric acid together with the uncrushed oxides resulting from the combustion in the ordinary way (on pure alundum) of twenty-two 2-gram samples of steels known to yield carbon upon reburning after pulverizing. Boiling the contents of the flask for several hours resulted in complete solution of everything except the mechanically held alundum, and during this time a current of air purified from carbon dioxide and monoxide was passed through the apparatus. The carbon dioxide found in the absorption tube was 0.00104 gram, which would correspond to 0.0007 per cent carbon on the basis of 44 grams of metal taken; the absorption tube for carbon monoxide showed none of this gas to be present. It seems fair to conclude from this experiment that any error in ordinary combustions resulting from occlusion or inclusion of carbon dioxide or monoxide is quite negligible. The case might be different where silica is used as supporting material for drillings, and there is consequently the possibility of forming viscous, slowly solidifying slags which might well retain large bubbles of gas. It should be noted in this connection that immediately after the combustion of metal has ceased the partial pressure of carbon dioxide and monoxide inside the combustion

[5] J. R. Cain, B. S. Tech. Paper No. 33; J. Ind. and Eng. Chem., 6, p. 465; 1914.
[6] Both palladium chloride and iodine pentoxide tubes were used.

tube reaches a maximum because the incoming oxygen has been almost completely consumed by the metal, leaving but little excess to sweep on the products of combustion; the oxides begin to freeze very soon after, and accordingly conditions are then very favorable for retention of carbon dioxide or monoxide by the solidifying oxides. However, as stated, when nonviscous, quickly solidifying oxides result, as in our experiment, the error from this cause may be regarded as negligible.

For carrying out combustions under the conditions selected by us—initial temperatures of 1050° to 1100° followed by tempera-

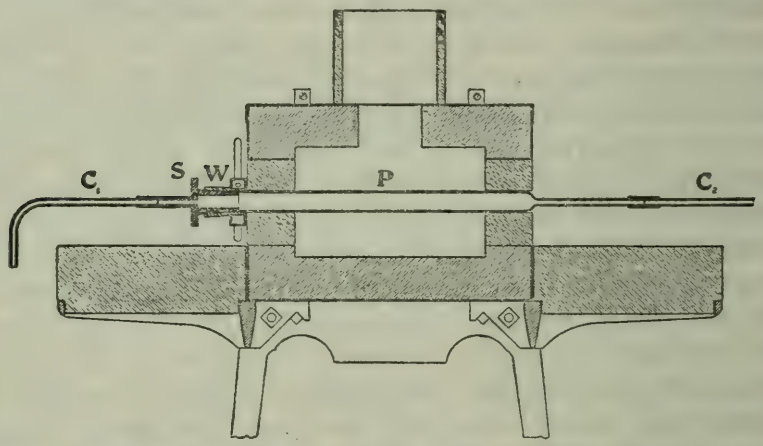

FIG. 1.—*Cross section of gas furnace.* C_1, C_2, *copper tubes soldered to platinum tube;* S, *German silver stopper;* W, *water jacket*

tures above 1450° and burning the metal directly supported on platinum—it was necessary either to start with low temperatures and slow oxygen current, increasing both as the skin of oxide on the grains became thick enough to protect the platinum, or else to burn initially in a furnace kept at the lower temperatures and then transfer the boat and contents to the high-temperature furnace. The first method was carried out in the gas furnace shown in Figs. 1 and 2;[7] the second procedure was used with our usual nichrome-wound furnaces in conjunction with the platinum-wound furnace shown in Fig. 3. In view of the failure to find notably higher results by our method (as will appear later), we did

[7] Reproduced from our first paper on high-temperature carbon combustions, above cited.

not deem it worth while to proceed to the next obvious step in apparatus—the construction of a single electric furnace suitable for both stages of the combustion. The electric-furnace method is very much to be preferred. The required temperatures are reached and maintained with much greater regularity and convenience than when gas is used, the wear on the platinum is less, and the chance for error from extraneous carbon dioxide is eliminated. The gas furnace is very destructive in its effects on the combustion tube, but the boats seem to suffer very little by either method. If, however, the operation of the gas furnace is conducted carelessly, so that the temperature initially is caused to rise too rapidly and the fusion temperature of the oxides is reached before all the iron is burned, then a boat is soon destroyed

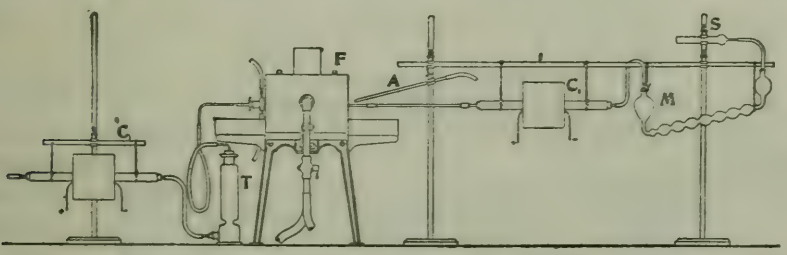

FIG. 2.—*Apparatus for high temperature combustions.* A, *air cooling tube;* C_1, C_2, *copper oxide catalyzers;* F, *gas furnace shown in Fig. 1;* M, *Meyer tube;* S, *soda lime tube;* T, *caustic potash jar*

by alloying with iron; this is also the case if the combustion of metal is incomplete in the first electric furnace when using that method. Temperatures were measured with a Wanner optical pyrometer and with a platinum-iridium thermo-element in conjunction with a millivoltmeter. The low-temperature electric furnace was maintained at 1050° to 1100°, the high-temperature electric furnace at 1475°; the gas furnace was started from room temperature and raised gradually to 1525°, at which temperature it was held during the fusion period. The copper oxide catalyzer following the furnace was found absolutely necessary when using the gas furnace, otherwise very large amounts of carbon monoxide were produced and escaped absorption; the low-temperature electric furnace also contained heated copper oxide in the forward portion of the (porcelain) combustion tube.

The routine followed in making a determination in the gas furnace consisted in inserting into the combustion tube the boat holding the sample and connecting up the Meyer tube containing barium hydroxide solution. While passing a slow current of oxygen the combustion tube was brought to 700° or 800° and kept within these temperatures for a minute or two until the superficial oxidation of the particles was effected; then the temperature was raised to 1050° or 1100° and the combustion of the iron completed. As soon as absorption of oxygen by the burning

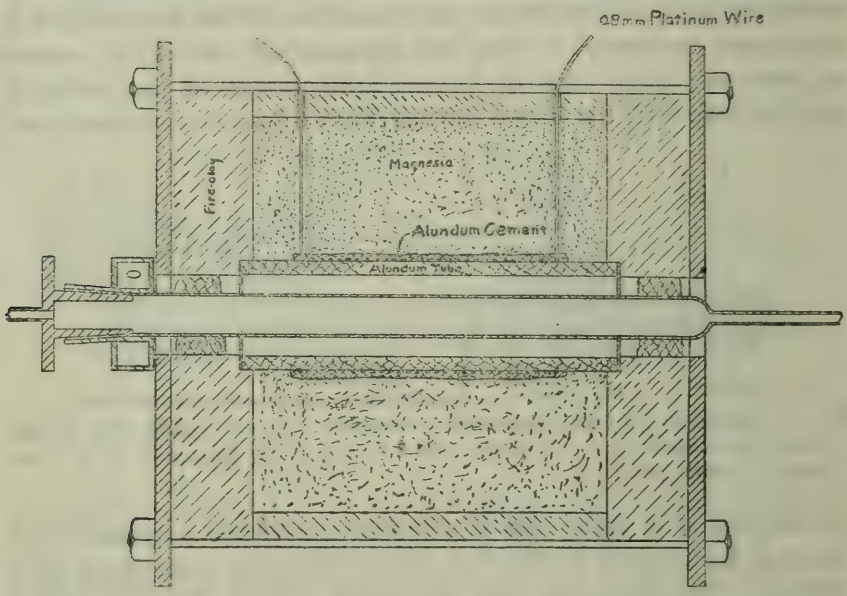

FIG. 3.—*Electric furnace for high temperature combustions*

metal had ceased the blowpipe flame was turned on full, this stage of the combustion being continued 25 to 30 minutes. The Meyer tube was disconnected and the determination finished by filtering off and washing the precipitated barium carbonate and titrating it against standard acid as described in the cited paper on this method. The procedure when using the electric-furnace method was to place the boat containing the sample in the already heated nichrome furnace, starting with a very slow current of oxygen, increasing gradually to the rate usually maintained and holding this condition until all the metal was burned and the carbon

dioxide swept out of the combustion tube. Then the connection of the Meyer tube was changed to the near-by high-temperature furnace through which oxygen was passing and the boat was transferred quickly to this furnace, which was maintained continuously at the proper temperature. After remaining in the high-temperature furnace 15 to 20 minutes the Meyer tube was disconnected and the filtration and titration finished as before. The oxides were usually found to be thoroughly fused and to have spread over the bottom of the boat; in some cases they even crept over the sides of the container. A second fusion of such oxides gave no further carbon dioxide to a freshly filled and clear barium hydroxide tube.

Great care was taken at all stages of the work to eliminate extraneous carbon dioxide or other substances that would cause a blank, so that, as already stated, the blank was always negligible. The frequent blanks which were made during this work were carried out (1) without any steel in the furnace; (2) when burning Bureau of Standards standard steel No. 23, which, as shown in the table of results in this paper, gives identical values when burned in the ordinary way and by our modified method. The fused oxides were readily removed from the boats, in preparation for the next combustion, by digesting in strong hydrochloric acid for a few hours.

The results in the table show that some steels give higher results by the new method than are shown on the certificates, others yield only slightly higher figures, and still others give the same results by both methods. We find it impossible to relate these three classes with the size of drillings used, with the carbon content of the sample, or especially with the presence or absence of the usual alloying elements. In only two cases were the results by the modified method as much as 0.02 per cent higher than the certificate value; with most of the other samples the difference was of the order of 0.01 per cent. Our work does not cover the Bureau's complete series of standard analyzed steels and irons, but the results are deemed quite representative, and we believe they are complete enough to justify us in the conclusion that the certificate values for these steels can not be affected with an error greater than 0.015 per cent (probably minus), and in most cases the error is much less. It is believed that such errors are negligible, considering the uses to which these standards are at present being put.

Results on Bureau of Standards Standard Irons and Steels

Description and Bureau of Standards number of sample	Certificate value for carbon—Average of all methods	Results obtained by combustion at high temperatures		Difference (average values—certificate values)
		Individual results	Average values	
Bessemer:				
0.1 per cent C, No. 8a	0.084	0.086	0.087	+0.003
		.088		
		.088		
		.086		
		.086		
0.4 per cent C, No. 10b	[a].373	.371	.372	−.001
		.370		
		.374		
		.374		
0.8 per cent C, No. 23	.805	.800	.805	.000
		.806		
		.805		
		.805		
		.804		
		.809		
		.805		
		.804		
B. O. H.:				
0.1 per cent C, No. 15a	.111	.116	.117	+.006
		.116		
		.118		
		.116		
		.118		
0.4 per cent C, No. 12a	.364	.379	378	+.014
		.379		
		.376		
		.376		
		.379		
0.8 per cent C, No. 14a	.815	.819	.816	+.001
		.816		
		.816		
		.816		
		.812		
A. O. H.:				
0.2 per cent C, No. 19a	207	.214	216	+.009
		.218		
		.218		
		.214		
0.6 per cent C, No. 21	.591	.602	.600	+.009
		.598		
		.602		
		.598		

[a] Certificate value, direct combustion, 0.363.

Results on Bureau of Standards Standard Irons and Steels—Continued

Description and Bureau of Standards number of sample	Certificate value for carbon—Average of all methods	Results obtained by combustion at high temperature		Difference (average values—certificate values)
		Individual results	Average values	
A. O. H.—Continued				
1 per cent C, No. 35	1.03	1.052	1.05	+0.02
		1.048		
		1.045		
		1.052		
		1.048		
Alloy steels:				
Chrome vanadium, No. 30	.373	.382	.379	+ .006
		.375		
		.379		
		.379		
		.381		
		.381		
		.379		
Chrome nickel, No. 32	.372	.383	.383	+ .011
		.380		
		.386		
		.383		
		.380		
		.383		
Chrome tungsten, No. 31	.599	.610	.609	+ .010
		.610		
		.608		
		.608		
		.612		
		.609		
		.609		
Nickel steel, No. 33	.278	.282	.285	+ .007
		.280		
		.289		
		.285		
		.288		
Vanadium steel, No. 24	.348	.350	.352	+ .004
		.350		
		.354		
		.353		
Irons:				
Iron C, No. 5b	2.726	2.74	2.743	+ .017
		2.75		
		2.74		
Iron D, No. 6a	2.46	2.48	2.48	+ .02
		2.48		
		2.48		

The experimental difficulties and the inconvenience of this method of determining carbon place it beyond the reach of most industrial and works laboratories, and we do not, therefore, recommend its use to such, except in the case of products for which it may be found better adapted than other methods.

WASHINGTON, November 3, 1915.

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DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 70

DURABILITY OF STUCCO AND PLASTER CONSTRUCTION

(PROGRESS REPORT CONTAINING RESULTS OF INVESTIGATIONS UP TO APRIL, 1916)

BY

R. J. WIG, Engineer Physicist
J. C. PEARSON, Associate Physicist
and
W. E. EMLEY, Associate Chemist
Bureau of Standards

In cooperation with an advisory committee composed of practical plasterers, representatives from Government offices, engineering societies, and industrial associations

ISSUED JANUARY 31, 1917

WASHINGTON
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1917

ADVISORY COMMITTEE

The advisory committee of the stucco and plaster investigation was organized in the spring of 1914, consisting of representatives of the various interests concerned (metal lath, cement, lime, gypsum, and hollow tile); also of representatives from the Bureau of Standards, the Supervising Architect's Office, and the American Concrete Institute. Three contracting plasterers of wide practical experience, recommended by and acceptable to the various interests on the committee, were also invited to serve.

The personnel of the committee as now organized is as follows:

R. J. WIG, Bureau of Standards, Washington, D. C.

J. C. PEARSON, Bureau of Standards, Washington, D. C.

W. E. EMLEY, Bureau of Standards, Pittsburgh, Pa.

H. B. MCMASTER, care of Berger Manufacturing Co., Canton, Ohio, formerly representing the Associated Metal Lath Manufacturers (resigned).

H. J. BROWN, Keystone Plaster Co., Chester, Pa., representing the Gypsum Industries Association. Alternate: D. L. Haigh.

H. S. SPACKMAN, 2024 Arch Street, Philadelphia, Pa., representing the Alca-Lime Manufacturers. Alternate: E. L. Conwell.

L. R. FERGUSON, 101 Park Avenue, New York, N. Y., representing the Portland Cement Association.

C. M. CHAPMAN, 37 Wall Street, New York, N. Y., representing the American Concrete Institute.

A. G. BAGNALL, 505 Hippodrome Prospect Building, Cleveland, Ohio, representing the Bagnall-Taylor Co., contracting plasterers. Alternate: J. C. Taylor.

WILLIAM O. HUMPHREYS, 1233 St. James Street, Philadelphia, Pa., representing John C. Humphreys & Son, contracting plasterers.

J. W. GINDER, Supervising Architect's Office, Treasury Department, Washington, D. C.

S. G. WEBB, 18 East Forty-first Street, New York, N. Y., representing the Gypsum Industries Association.

W. E. CARSON, Riverton, Va., representing the National Lime Manufacturers Association.

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N. G. HOUGH, manager Hydrated Lime Bureau of the National Lime Manufacturers Association, Arrott Building, Pittsburgh, Pa.

C. B. ASHER, manager National Fireproofing Co., Woodward Building, Washington, D. C., representing the Hollow Building Tile Manufacturers' Association of America.

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DURABILITY OF STUCCO AND PLASTER CONSTRUCTION

By R. J. Wig, J. C. Pearson, and W. E. Emley

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I. INTRODUCTION

The unquestioned popularity of the so-called "stucco"[1] house in recent years has given rise to a comparatively rapid development of a type of building construction, not entirely new by any means, but characterized by the use of new methods and new materials. The rapid adoption of this new construction has been due to many conditions, among which may be mentioned the desire for a cheap but fire-resistive type of structure, the increase in price and decrease in quality of lumber, the development in the use of Portland cement, and the production of metal lath, hollow building tile, and other materials; but perhaps most of all to the fact that the stucco house appeals to the prospective home builder, because of its generally attractive appearance and anticipated low maintenance.

There have been, however, many total or partial failures of stucco and many letters have been received by the Bureau for information regarding the best methods of application, and the probable

[1] The word "stucco" as used in this report may be defined as a material used in a plastic state to form a hard coating for the exterior walls or other exterior surfaces of any building or structure. "Stucco" as here used is a mixture of one or more cementitious materials, with sand or other fillers and with or without other materials, such as hair, coloring matter, etc. The word "stucco" is used without regard to the composition of the material, defining only its use and location of its use, as contrasted with the words "plaster" and "mortar."

permanency and durability of good stucco construction. In 1910 the Associated Metal Lath Manufacturers, because of cases of corrosion in metal-lath construction, particularly in cases where the metal was not protected by painting or galvanizing and the stucco was of doubtful quality, and believing that the majority of failures were due to careless construction, requested the cooperation of the Bureau in determining experimentally what protective measures would insure reasonable durability of the metal lath under stucco and plaster.

In compliance with this request the Bureau planned a preliminary series of exposure tests which eventually took form in the erection of some 300 panels of metal lath, 18 by 24 inches, plastered with various combinations of the commonly used plastering materials, viz, cement, lime, and gypsum. Approximately one-half of the total number of panels formed a part of the exterior walls of a storage building on the Bureau grounds, and the remainder were erected on interior partitions. A fair idea of the exposure of these panels may be obtained from Figs. 1 and 2. These panels were erected in the fall of 1911. Two years later a careful inspection was made and a summary of the results, together with a full description of the tests was presented at the meeting of the American Concrete Institute, February, 1914.[2]

It is to be borne in mind that these tests were primarily comparative corrosion tests of metal lath, and the results obtained indicated that, irrespective of the type of plastering material, the lath which was galvanized, whether cut from galvanized sheets or galvanized after expansion, was in the best condition, whereas the uncoated plain steel lath was in many cases badly corroded. The apparent order of excellence of the various classes of lath determined at that time and confirmed by subsequent observation was as follows: Galvanized after expansion, cut from galvanized sheets, painted ingot iron, painted steel, sherardized steel, plain ingot iron, and plain steel.

It was also the purpose of the tests to determine in so far as possible the protective qualities of different stuccos and plasters; but as indicated in the progress report of the tests, a number of the mixtures were criticized as being oversanded, and the comparative results in this respect were therefore open to question. These tests were severely criticized by some manufacturers and therefore it was decided to immediately outline a more comprehensive series of tests on a much larger scale. In order that the

[2] Jour. Am. Conc. Inst., Vol. 2, p. 445, November, 1914; also Concrete-Cement Age, Vol. 5, p. 38, July, 1914.

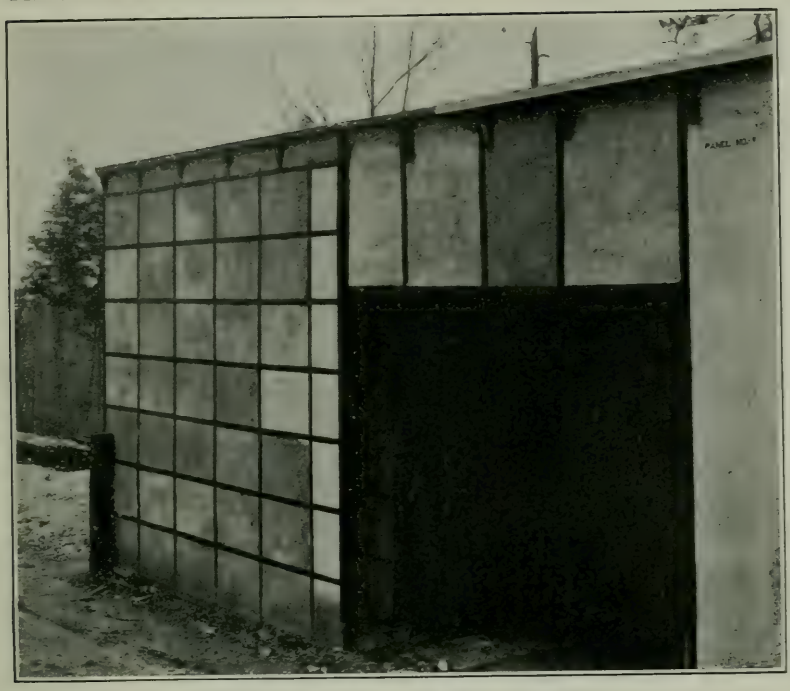

FIG. 1.—*North wall of test panels erected in 1911*

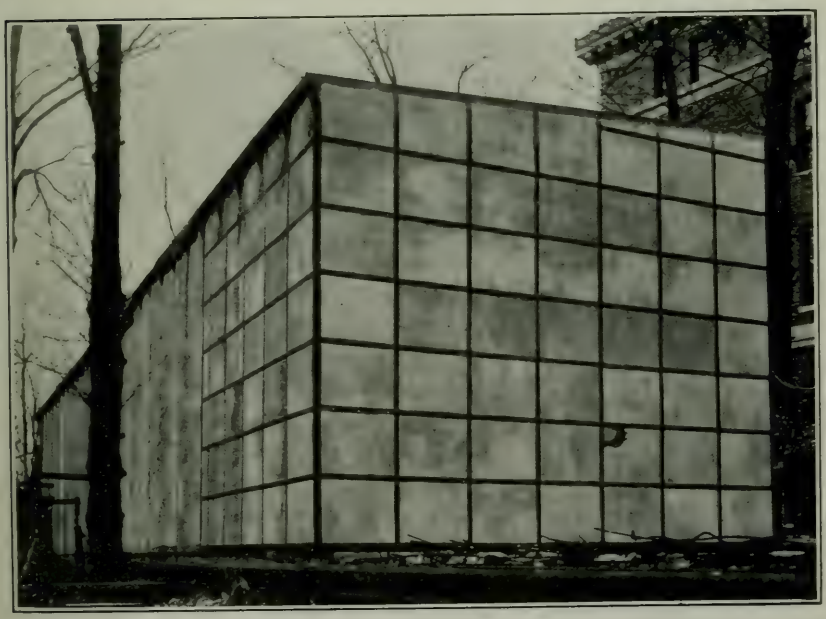

FIG. 2.—*South and east walls of the test panels erected in 1911*

further work should be carried out efficiently and should preclude as far as possible all subsequent criticism of materials, proportions of plaster ingredients, construction, and workmanship, it was decided to place the entire program in the hands of a committee invited by the Bureau to act in an advisory capacity and to inspect and be responsible for the satisfactory construction of the test panels.

Thus originated the plan of the present cooperative stucco and plaster investigation, of which the tests briefly described in the foregoing paragraphs constitute only a preliminary investigation. These preliminary tests are still in progress and will be concluded in the course of the next year or two when it becomes necessary to remove the building of which the panels form a part. The new series of tests embraces at the present time only that part of the investigation relating to exterior stuccos, a complete description of which is presented in this report.

II. SCOPE OF INVESTIGATION

The members of the advisory committee were unanimously of the opinion that the proposed investigation should not be limited to tests of stucco and plaster on metal lath but should include, in so far as possible, all the common types of both exterior and interior plastering. It was believed that plastering faults directly due to corrosion of embedded metal are a comparatively small portion of all the objectionable features, which are generally indicated by the development of cracks with consequent disfiguration and gradual disintegration of the plaster coating. A study of the origin and methods of prevention of cracks in various types of plaster is therefore one of the chief purposes of the investigation.

The committee decided unanimously that the test panels should be of large size, not only to enable the plastering to be done on a scale comparable with that of ordinary residence construction but also large enough to contain window and door openings, at which structural cracks, or cracks due to expansion and contraction of the stucco or plaster, are most likely to develop. The size of exterior panel eventually decided upon was approximately 15 feet long by 10 feet high. Since the very large number of possible combinations, or even desirable combinations, of different stuccos on different bases would, on this plan, require an enormous test structure, it was decided to select approximately 50 of the most typical combinations and embody these in construction on the walls of a building erected in such manner as to compare favorably in rigidity and solidity with good residence construction, and allow a variety

of base materials, such as wood and metal lath, hollow terra-cotta tile, gypsum block, gypsum plaster board, brick, concrete block, "Bishopric Board," etc. If cracks eventually developed which were evidently due to structural faults, such as insecure foundations or imperfect framing or bracing, an endeavor would be made to distinguish such cracks from others resulting solely from the failure of stucco materials. The test structure would also be available for the erection of interior plasters, although this branch of the investigation was not to be undertaken until after the exterior stucco investigation was well advanced.

In view of the limited number of large-size panels the plan of the investigation also calls for supplementary field work, this to be carried on as opportunity offers and to follow such lines as may be suggested by developments in the test panels.

The general scope of the investigation as thus outlined can be conveniently elaborated by reference to the following list of exterior panels which was gradually developed by correspondence and conference with the advisory committee during the year following its organization. In this program the proportions given for the various stucco mixtures are those recommended by the representatives of the various manufacturing organizations, who were also invited to furnish such materials for the tests as they desired, provided this was acceptable to the committee as a whole. While in some respects this arrangement is more open to criticism than that of purchasing the materials in the open market, the manufacturers thus had the privilege of submitting materials which they knew to be satisfactory and which would presumably represent the best that could be obtained. Under the supplementary tests of materials described later, detailed information is given as to the source of all materials used.

III. LIST OF EXTERIOR PANELS INCLUDED IN INVESTIGATION

In the following list of panels all proportions are by weight unless otherwise specified, three coats to be applied over wood and metal lath, two coats over all other bases; hair to be used only in Groups I, III, and IV unless otherwise specified. The several types of stucco are referred to by letters as follows:

Cement Lime

A–1. First coat. 1 part cement, 0.10 part high magnesian hydrated lime, 3 parts sand, 0.05 part hair, by weight. Second coat. Same as first coat, without hair. Third coat. Same as second coat, sand float finish.

A–2. First coat. 0.75 part cement, 0.25 part high magnesian hydrated lime, 3 parts sand, 0.05 part hair. Second coat. Same as first coat, without hair. Third coat. Same as second coat, sand float finish.

A–3: Same as 1 except high calcium hydrated lime to be used instead of magnesian hydrated lime.

A–4: First coat. 1 part cement, 0.10 part high magnesian hydrated lime, 4 parts sand, 0.05 part hair, by weight. Second coat. Same as first coat, without hair. Third coat. Same as second coat, sand float finish.

Lime Cement

B–1: First coat. 0.25 part cement, 0.75 part high calcium hydrated lime, 3 parts sand, 0.075 part hair, by weight. Second coat. 0.25 part cement, 0.75 part high calcium hydrated lime, 4 parts sand, by weight. Third coat. Same as second coat, sand float finish.

B–2: Same as 1 except high magnesian hydrated lime to be used in place of high calcium hydrated lime.

"Alca" Lime

C–1: First coat. 1 part Alca lime, 3.5 parts sand, 0.075 part hair, by weight. Second coat. 1 part Alca lime, 4 parts sand, by weight. Third coat. Same as second coat, sand float finish.

C–2: First coat. 0.75 part Alca lime, 0.25 part cement, 3.5 parts sand, 0.075 part hair, by weight. Second coat. 0.75 part Alca lime, 0.25 part cement, 4 parts sand, by weight. Third coat. Same as second coat, sand float finish.

Straight Cement

D–1: First coat. 1 part cement, 2.5 parts sand, by weight. Second coat. Same as first coat.

D–2: First coat. 1 part cement, 2 parts sand, 0.05 part hair, by weight. Second coat. 1 part cement, 3 parts sand, by weight. Third coat. Same as second coat, sand float finish.

D–3. First coat. 1 part cement, 3 parts sand, 0.05 part hair, by weight. Second coat. Same as first coat, without hair. Third coat. Same as second coat, sand float finish.

Half-and-Half Cement Lime

E: First coat. 0.5 part cement, 0.5 part high magnesian hydrated lime, 3 parts sand, 0.05 part hair, by weight. Second coat. 0.5 part cement, 0.5 part high magnesian hydrated lime, 4 parts sand, by weight. Third coat. Same as second coat, sand float finish.

STUCCO WITH INTEGRAL WATERPROOFING

F–1: Calcium soap type ("Medusa"). First coat. 1 part cement, 3 parts sand, 0.05 part hair, 0.02 part Medusa, by weight. Second coat. Same as first coat, without hair. Third coat. Same as second coat, sand float finish.

F–2: Asphaltic emulsion type ("Impervite"). Same mixture as (1) except Impervite to be used in place of Medusa, using 1 gallon (9 pounds) per bag of cement.

WHITE PORTLAND CEMENT

G–1: First coat. 1 part gray cement, 3 parts sand, 0.3 part high magnesian hydrated lime, by weight. Second coat. 1 part white cement, 2 parts white silica sand, 0.1 part high magnesian hydrated lime, by weight, sand float finish.

G–2: First coat. 1 part gray cement, 3 parts sand, 0.1 part high magnesian hydrated lime, 0.05 part hair, by weight. Second coat. Same as first coat, without hair. Third coat. 1 part white cement, 3 parts limestone screenings, 0.1 part high magnesian hydrated lime, by weight, float finish.

PANELS

Group I

Plastered one side over sheathing and sheathing paper, ½-inch crimped galvanized furring, 12 inches o. c. More or less air space between plaster and sheathing.

Panel 1, expanded metal lath, diamond type, 26 g galvanized, one-half before and one-half after expansion, stucco A–1; panel 2, expanded metal lath, diamond type, 24 g painted, stucco A–1; panel 3, expanded metal lath, diamond type, 24 g painted, stucco B–2; panel 4, expanded metal lath, diamond type, 24 g painted, stucco C–1; panel 5, expanded metal lath, diamond type, 24 g painted, stucco D–2; panel 6, expanded metal lath, diamond type, 24 g painted, stucco D–3; panel 7, expanded metal lath, diamond type, 24 g painted, stucco F–1; panel 8, expanded metal lath, diamond type, 24 g painted, stucco F–2; panel 55, expanded metal lath, diamond type, 24 g painted, stucco C–2; panel 9, wire lath, 20 g galvanized after woven, stucco A–2.

Group II

Plastered one side over sheathing and sheathing paper, ½-inch crimped galvanized furring, 12 inches o. c. No hair used in any coat, plaster pushed through to thoroughly embed lath.

Panel 10, expanded metal lath, 24 g diamond type painted, stucco A–1; panel 11, expanded metal lath, 24 g diamond type painted, stucco B–2; panel 54, expanded metal lath, 24 g diamond type painted, stucco A–1, to be coated with cement gun; panel 12, wire lath, 20 g galvanized after woven, stucco A–1; panel 13, expanded metal lath, 26 g galvanized, one-half before and one-half after expansion, stucco C–1 (use limestone screenings in finish coat).

Group III

One-half inch crimped galvanized furring attached to studs 12 inches o. c. No sheathing, lath back plastered. Outer faces of studs coated with "hydronon."

Panel 14, expanded metal lath, ribbed type, 27 g painted, stucco G–2; panel 15, expanded metal lath, ribbed type, 27 g painted, stucco A–1; panel 16, expanded metal lath, ribbed type, 27 g painted, stucco B–1; panel 17, wire lath, 20 g galvanized after woven, stucco E.

Group IV

Wood lath over sheathing and sheathing paper, ⅜ by 1¼ inch wood furring, 12 inches o. c. Plain lathing.

Panel 18, spruce lath, uncoated, stucco A–3; panel 19, spruce lath, uncoated, stucco B–2; panel 20, spruce lath, coated with "hydronon," stucco B–2.

Group V

Wood lath over sheathing and sheathing paper, no furring, counter lathing.

Panel 21, spruce lath, uncoated, stucco A–3; panel 22, spruce lath, uncoated, stucco B–1; panel 23, spruce lath, uncoated, stucco C–1; panel 24, spruce lath, coated with "hydronon," stucco A–3; panel 25, spruce lath, coated with "hydronon," stucco B–1.

Group VI

Plaster board, ⅜ inch thick, nailed to studs 12 inches o. c. Four-inch spacing of nails, ¼ inch between boards.

Panel 26, perforated, one-half felt, one-half chip surface, stucco A–1; panel 27, perforated, "parlocked," stucco A–1; panel 28, unperforated, one-half felt, one-half chip surface, stucco A–1; panel 29, unperforated, "parlocked," stucco A–1.

Group VII

Tile (terra-cotta tile to be hard burned, with dovetail ragged scoring).

Panel 30, concrete block, lower half rough block, upper half smooth block; left half to be wetted and right half to be wetted and grouted before plastering with stucco A–1; panel 31, terra-cotta tile, stucco A–1; one-half to be plastered with haired mortar, one-half without hair; panel 32, terra-cotta tile, stucco B–1; panel 33, terra-cotta tile, stucco C–1; panel 34, terra-cotta tile, stucco D–1; panel 35, terra-cotta tile, one-half glazed tile, all covered with ¾-inch wire mesh, stucco A–1; panel 36, terra-cotta tile, one-half painted with bituminous material, stucco A–2; panel 37, terra-cotta tile, one-half painted with bituminous material, stucco G–1; panel 38, glazed tile, one-half painted with bituminous material, stucco A–1 (panels 36, 37, and 38 to be one-fourth "parlocked" and one-fourth coated with "antihydrine"); panel 53, terra-cotta tile, stucco A–1; to be coated with cement gun.

Group VIII

Brick, common rough, hard-burned brick to be used.

Panel 39, brick, stucco A–1, one-half plastered with haired mortar, one-half without hair; panel 40, brick, stucco B–2; panel 41, brick, painted, plaster keyed with two bituminous materials, stucco A–1.

Group IX

Gypsum block.

Panel 42, smooth block "parlocked," stucco A–1; panel 43, corrugated block, "parlocked," stucco A–1; panel 44 corrugated block, uncoated, stucco A–1.

Group X

Monolithic concrete.

Panel 45, smooth, "parlocked," stucco A–1; panel 46, panel to be divided into four vertical sections, *a*, *b*, *c*, *d*—(*a*) to have surface untreated in any way, (*b*) to have surface grouted but not mechanically roughened, (*c*) to have surface wire brushed only, (*d*) to have surface wire brushed and grouted (all to be plastered when concrete is green with stucco A–1); panel 47, panel to be divided into three vertical sections, *a*, *b*, *c*—(*a*) to be roughened with pick or other suitable tool, (*b*) to be scrubbed with 1:4 muriatic acid solution, (*c*) to be scrubbed with equivalent acetic acid solution (all allowed to dry before any treatment, stucco A–1); panel 48, cement gun on concrete, stucco A–1; panel 49, half as forms are removed without treatment, half with wire brush, stucco C–1; panel 50, concrete, upper half as forms are removed, lower half wire brushed, left half thin coated with 1:1 grout, right half thin coated with 1:2 grout, stucco A–1.

Group XI

Miscellaneous.

Panel 51, "Bishopric board," one-half creosoted lath, one-half uncreosoted lath, stucco A–1; panel 52, same as 51, but plastered with stucco B–1; panel 53, see Group VII; panel 54, see Group II; panel 55, see group I; panel 56, "Clinton Welded Sheathing" applied directly to studs, stucco A–4.

The preceding outline will indicate that the committee has endeavored to arrange the panels in groups according to the bases on which the stuccos are applied. The number of panels in the different groups is proportioned, roughly, by the probable extent to which similar construction is used throughout the country, although this number is augmented or decreased according to the importance of certain groups or for the purpose of introducing special tests where found desirable. Thus, since metal lath is used most extensively, the first three groups comprise three different types of construction on metal lath as a base and each having certain advantages. It should be stated, in order to avoid a misconception of the purpose of the tests, that while comparisons between various groups and individual panels are always possible, it has been the sense of the committee that each panel should stand primarily on its own merits as representative of a certain type and method of construction, and its eventual condition and rating should be established without reference to any other panel. Thus the metal-lath panels are for the most part made up of painted steel because this class of material is recommended by the lath manufacturers (the uncoated steel is not recommended). The painted steel is very widely used, and is much less expensive than galvanized lath. On the other hand, a few panels of galvanized lath have been introduced as typical of the best in metal-lath construction.

Group I typifies a form of construction of exterior stucco in which more or less air space is designedly introduced between the plaster and sheathing, and affords a direct comparison of several different stuccos. In Group II the air space is eliminated for the purpose of better embedding the metal in mortar, the insulating value of the air space being sacrified for the added protection to the lath. Group III affords a still heavier coating of mortar over the lath, this method eliminating the cost of sheathing and insuring good protection for the metal fabric, but sacrificing to some extent the rigidity and insulation contributed by the sheathing. In good construction of this type, special measures are necessary for taking care of these two features.

Wood lath is probably used to a much greater extent for exterior stucco than the number of panels in Group IV would indicate. The committee was divided in its opinion as to the suitability of wood lath for this purpose, however, and as the counter lathing seemed to be more favored than the plain lathing, a larger number

of panels were assigned to Group V. To determine if possible whether a bituminous coating on the wood lath would affect the durability of the stucco, one panel of Group IV and two of Group V were coated with "hydronon" (a bituminous paint). The distribution of the two types of stucco containing a large proportion of Portland cement in one and of hydrated lime in the other (A–3 and B–1, respectively) on the wood-lath panels is such as to afford a direct comparison between the coated and the uncoated wood lath.

Groups VI and IX may be regarded as experimental groups introduced at the special request of the Gypsum Industries Association, rather than as examples of common construction. These materials are used to some extent, but not widely, for exteriors, and the seven panels of these two groups embody the experimental variations recommended by the association.

Group VII contains a larger number of panels than was originally assigned to hollow tile. This group was enlarged for experimental purposes in view of the fact that the use of this material for stucco houses is rapidly increasing and because a number of cases have been reported in which this type of construction has not been satisfactory. Of the 10 panels in this group 1 is of concrete block, 5 offer a direct comparison of different stuccos, and 4 show variations in material or treatment with a view to improving adhesion or eliminating cracks.

Only three brick panels were included in Group VIII, in accordance with the opinion of the committee that brick is one of the most satisfactory bases for stucco and that information regarding this type of construction can readily be obtained in the field. Two of the brick panels represent the ordinary specified construction for stucco, one having a high cement and the other a high lime content; the third was designed to represent an old painted wall on which the plaster bond was to be supplied by two types of bituminous material. The brick base of this panel did not dry out sufficiently to warrant painting before cold weather and is consequently unfinished at the present time.

Group X includes a number of experimental variations in the treatment of monolithic concrete for the purpose of observing what methods are likely to give satisfactory adhesion of a plaster coat to the concrete. It may be remarked that this group is important rather in its relation to the decorative treatment of retaining walls, bridges, large residences, storehouses, warehouses, and other

monolithic structures than in connection with ordinary residence construction. Three of the panels of Group X are representative of walls that have hardened and dried out before plastering, and three of freshly molded walls.

Group XI includes three panels of special proprietary materials, substitutes for wood or metal lath, included upon recommendation of the advisory committee.

As indicated by the list of panels, the experimental part of the investigation is confined mainly for the present to a study of typical stuccos on the bases commonly used, namely, wood and metal lath, brick, tile, and concrete. There has been no intention of going into the possible or desirable variations in surface treatment of stuccos nor into the use of waterproofing to any extent. The sand-float finish has been uniformly used throughout because it is commonly used in practice and because it is well adapted to the detection of small defects. Comparatively few proprietary materials have been used, and only two stuccos include any special waterproofing treatment. It has been the opinion of the committee that the investigation of waterproofing and decorative surface treatments can not be satisfactorily undertaken as a part of the one already outlined, and that if these features are to be considered later they should be taken up as separate investigations and should be based on as complete a knowledge as possible of the causes and prevention of failures in the untreated stuccos. Accordingly the experimental work already undertaken largely avoids integral and special surface treatments, although such information as is available will be obtained as opportunity offers in the field work of the present investigation.

IV. CONSTRUCTION OF THE TEST STRUCTURE

A fairly good idea of the test structure may be obtained from the photographs, Figs. 3 and 4. The structure is approximately 200 feet long, 26 feet wide, and 25 feet high (above grade), of two stories, covered with a low hip roof, and ornamented with cornice and pilasters. Level ground not being available, the structure is located on a hillside, which in the process of other construction work had been covered with 10 to 15 feet of soft clay fill. Some excavation was necessary at the north end of the structure, but the south end overhangs the slope of the hill and is supported on a steel-frame foundation resting on concrete footings. A portion of the steelwork is shown in Fig. 3. As the peculiar ground conditions and the nature of the foundation may naturally suggest the

FIG. 3.—*The new test structure from the southeast*

FIG. 4.—*General view of the new test structure from the northwest*

possibility of settlement or lateral movement in the structure, the foundation layout may be described somewhat more in detail.

With reference to Fig. 5 it will be observed that the foundation plan is in the form of a grid of 12 sections, each 16 feet 6 inches by 24 feet 8 inches, these measurements being taken to the center of

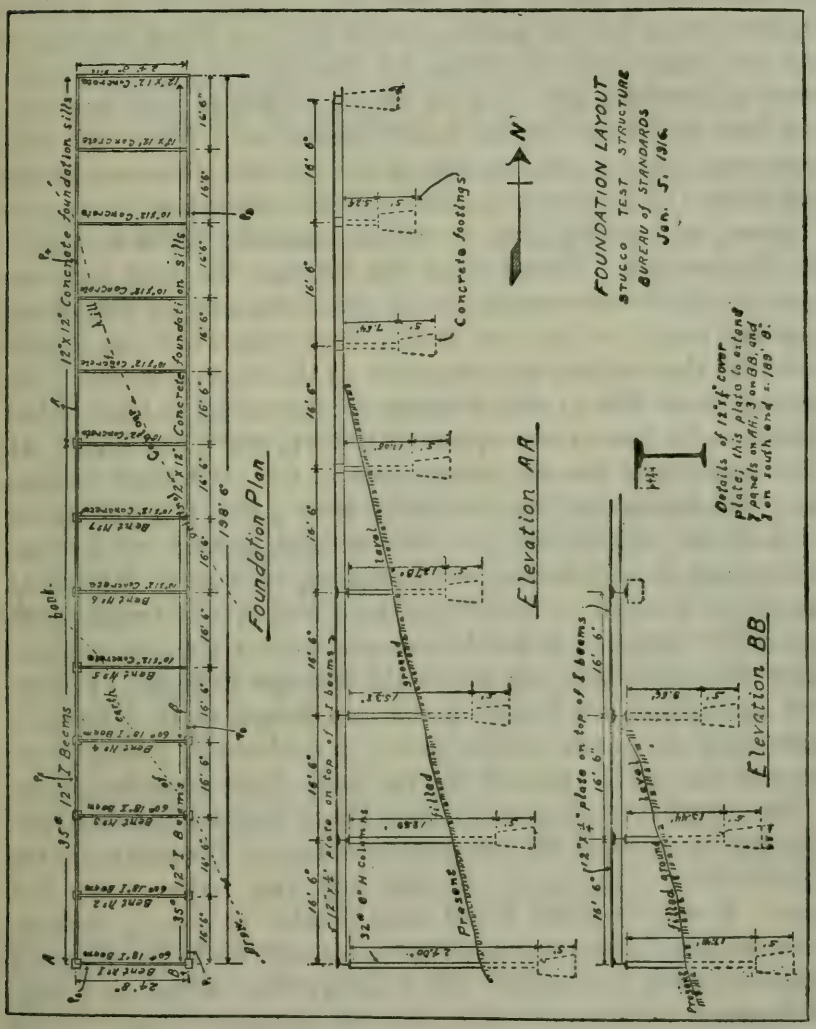
FOUNDATION LAYOUT
STUCCO TEST STRUCTURE
BUREAU of STANDARDS
Jan. 5, 1916.
Foundation Plan
Elevation AA
Elevation BB
Concrete footings
12"x12" Concrete foundation sills
35# 12" I Beams
Details of 12"I" cover plates; this plate to extend 2 panels on AA, 3 on BB, and 1 on south end of 198' 6"
N

FIG. 5.—*Foundation plan of test structure*

the frame of the superstructure. These sections correspond to the 12 rooms into which the first story of the structure is divided, as explained below. Of the 12 sections of sill on the west side, 7 are 35-pound, 12-inch I beams and 5 are 12 by 12 inch concrete sills. On the east side, the south 3 sections are of steel and the remaining 9 of concrete. Of the 13 cross sills, the south 4 are

60-pound 18-inch I beams and the remainder are of 10 by 12 inch concrete. As shown by the space between the dotted lines, a large portion of the center of the structure rests on earth fill, which is very dense and well packed under the east sill, but is softer under the west sill. On the west side, therefore, all footings at the intersections are set approximately 3 feet below the original ground surface and the same is true of the three south footings on the east side. (See elevations AA and BB, Fig. 5.) Furthermore, all concrete sills lying on fill are reinforced with four one-half inch round rods as an added precaution. Where the concrete cross sills join the steel sills on the west side, these reinforcing rods extend through corresponding holes in the web of the 12-inch I beams, and having been previously threaded serve as ties at the intersections. Longitudinal ties between the steel and concrete portions of the foundation are provided partly by reinforcing rods, but mainly by the 2 by 10 inch floor joists which run lengthwise with the building and are spiked to the transverse sills. The footings under the 10 steel columns are pyramidal in form, 3 feet square at the base, 2 feet square at the top, and 5 feet high. All other footings at the sill intersections in the earth-filled sections are 3 feet square and vary in height from 2 to 6 feet, depending on position. Where sills are laid on solid ground, no footings were placed at intersections nor reinforcing rods used. The south end of the foundation is stiffened with four sets of bracing consisting of 1⅛-inch turnbuckle rods attached to the columns just below the girders and just above the concrete footings. Twelve-inch steel plates are riveted to the top flanges of the 12-inch I beams and the south 18-inch girder to conform in width to the concrete sills and to provide for the water table described below.

The plan of the test structure calls for 22 masonry panels which, with the exception of the two panels containing the doors, are the total number of panels in the east and west walls on the first story. It was therefore found most feasible to erect a skeleton frame of 6 by 6 inch Georgia pine posts and fill in the masonry panels between the posts. The masonry thus serves as a base for the second story, which is entirely of frame construction. Three by 6 inch wood sills were first bolted to the 13 transverse foundation sills, on which rise 2 by 6 inch partition studs to the height of the first story. The 6 by 6 inch posts were set at the ends of each transverse sill and rise to the full height of the building. Fig. 6 is a section of the structure showing the construction at an interior partition and the method of transverse bracing. It may

also be noted with reference to Fig. 6 that the floors, interior partitions, and floor loads are carried mainly by the transverse sills, the exterior walls and roof by the longitudinal and two end sills.

The frames of the interior partitions were first erected and braced longitudinally with temporary braces while the masonry panels were being constructed. These panel walls are nominally 8 inches thick (the brick and gypsum block being slightly more than this) and rest directly on the longitudinal sills without special anchorage, but spikes are set in all joints where the masonry

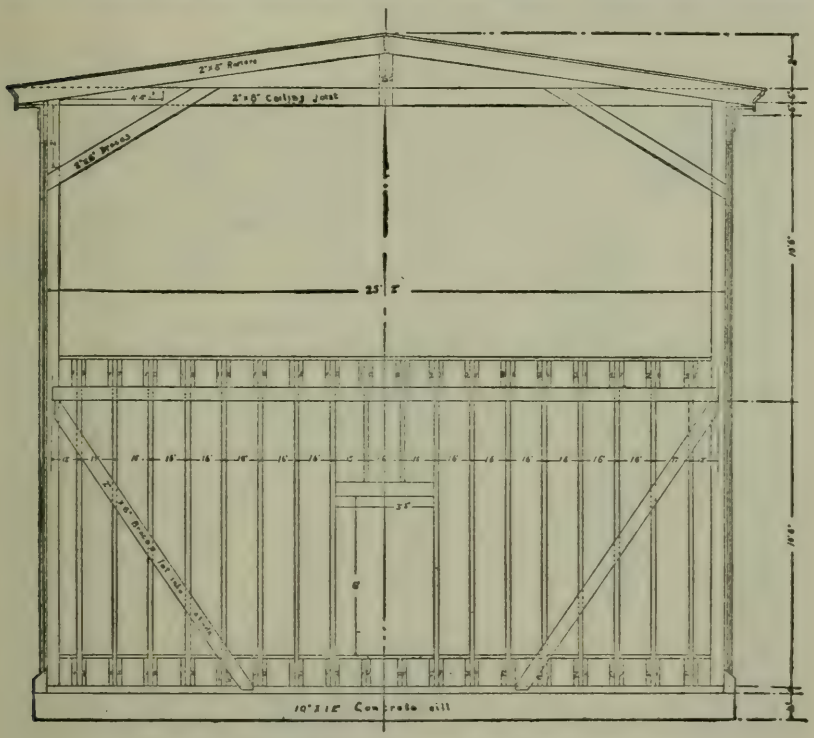

FIG. 6.—*Section of test structure at an interior partition*

joins the skeleton frame. When the masonry panels were brought to their full height, 3 by 6 inch wood sills were then fastened along the top by means of anchor bolts, and also spiked to the 6 by 6 inch posts. On these sills rise the 2 by 6 inch wall studs of the second story.

The framing of the north and south ends and of the door panels is similar to that of the second story, except in this case the studs run the full height of the building. The north end elevation is shown in Fig. 7, the western half of which shows the method of framing and bracing. Both north and south ends are unsheathed.

The former carries the four panels of back-plastered metal lath of Group III, the latter the four panels of plaster board (Group IV) which is nailed directly to the studs. It should be noted here that the bridging shown between the studs on the end sections was omitted, the oversight not being discovered until the plastering was nearly completed. As it seemed unwise to attempt to cut in this bridging after the plastering was completed, 8-inch sheathing was spiked across the interior faces of the studs where the bridging should have been, to prevent as far as possible any twisting of the studs between floors.

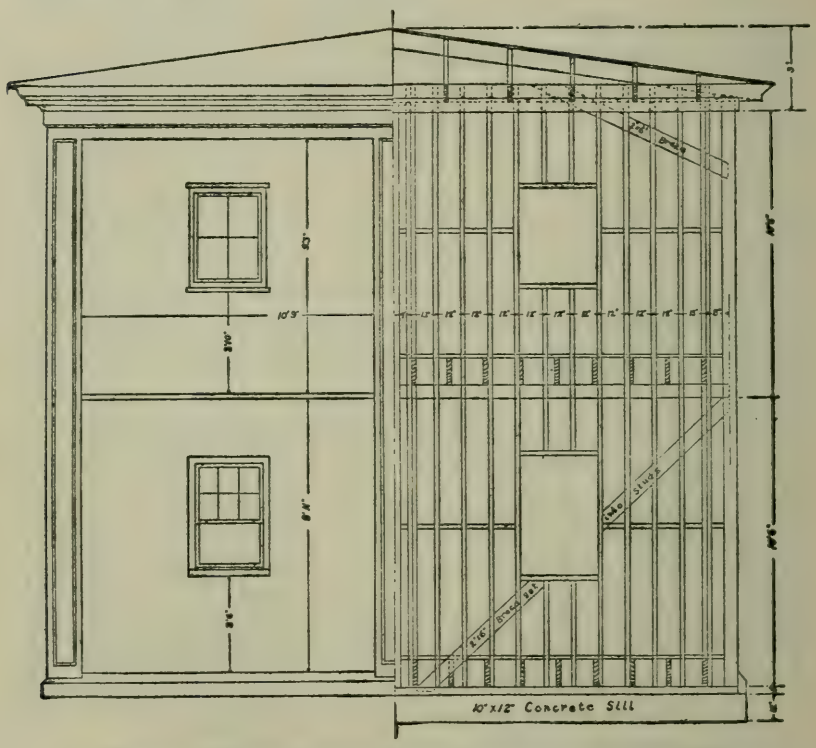

FIG. 7.—*North elevation of test structure showing framing of ends*

Fig. 8 shows the construction of two typical wall sections. In further explanation it should be stated that longitudinal bracing is supplied by the diagonal sheathing securely nailed at each stud and 6 by 6 inch post, and covering the entire east and west walls of the second story, with the exception of the south-end panel on the west side.

The roof construction is evident from Figs. 6, 7, and 8. It is supported on a 2 by 6 inch collar beam spiked to the outside of each

wall stud and 6 by 6 inch post. The roof trusses are made up of the rafters and ceiling joists as shown in Fig. 6, solidly spiked together where these overlap, and braced at the center. The ceiling joists are notched over the supporting collar beams and are cut to serve as a partial support for the cornice. The roof is of ⅞-inch plain

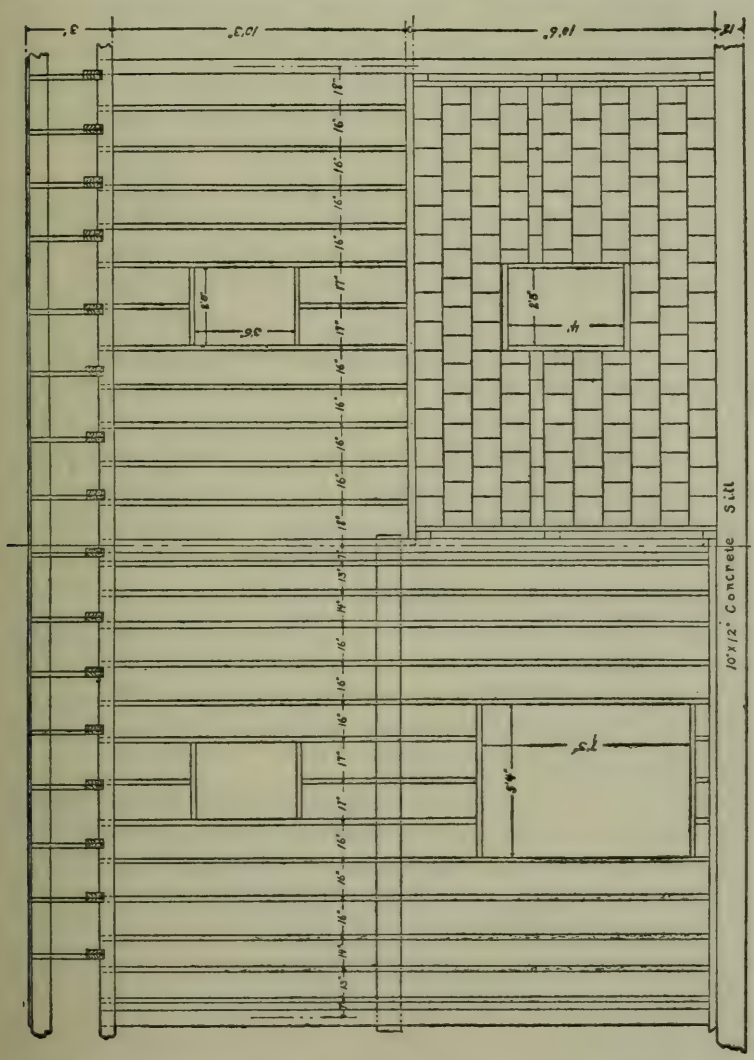

FIG. 8.—*Two typical wall sections of test structure, showing the north door panel (No. 52), the adjacent tile panel (No. 33), and the two second-story frame panels (Nos. 9 and 10)*

dressed sheathing, covered with heavy-weight "ruberoid" sheet roofing fastened with "holtite" fasteners, according to the recommendation of the manufacturers. The roof projects slightly over the cornice, an efficient drip being provided by galvanized-iron flashing extending ⅜ inch below the undersurface of the sheathing. In

this manner the cornice and upper edges of the second-story panels are well protected. No gutters are provided, in order that the drip from the roof may be allowed to strike the face of the panels whenever weather conditions permit.

To protect the bases of the first-story panels from ground moisture a continuous water table of brick and cement mortar was first laid on the foundation sills and rises to a height of 9 inches on the faces of the masonry panels. The vertical surface of the table, which is flush with the outer surface of the foundation sill, rises to a height of 6 inches above grade and is then beveled inward.

The bases of the pilasters were cut to the slope of the water table and erected after the completion of the water table and cornice, but prior to lathing and plastering. The pilaster posts are rabbeted to project over the edge of the stucco. A 2-inch wood strip divides the first and second story panels as shown in Fig. 7. The outer face of the strip is flush with the face of the stucco and the lower edge of the strip is provided with a galvanized lip to prevent water getting behind the stucco of the lower panels.

As shown in Fig. 8, the windows are small and of ordinary types. The second-story windows are outswing casements hinged at the top, provided with projecting caps and sills. The cap flashing is similar to that used at the eaves, and the sills are provided with drip grooves and also flashing similar to that used on the belt course. The side trim of these windows is flush with the face of the stucco. The first-story windows are of the double-sash type, recessed on the masonry panels, but provided with flashed caps and sills on the north and south ends of the building where the wall construction is similar to that of the second story.

The foregoing description of the construction of the test structure is intended only to cover those details which may have some bearing on the durability of the panels. While it is believed that the foundations are firm and the bracing sufficient to prevent swaying, six reference marks have been established for the purpose of detecting settlement and lateral movement of the base. The marks consist of steel pins set at different points in the water table where movement would be most likely to occur and are indicated on the foundation plan at the points P_1, P_2, etc., Fig. 5. Levels will be taken on these pins from time to time and compared with the original measurements taken soon after the building was completed. At the present time no structural cracks have been observed in the masonry panels, which indicates that the foundation has not moved to an appreciable extent.

V. DETAILED DESCRIPTION OF PANELS

The following descriptive list of the test panels is intended to include in condensed form all the essential information regarding the location and construction of the individual panels, together with notes on the erection, condition of the plaster coats, and other pertinent items up to April, 1916. To avoid unnecessary repetition, however, certain general conditions may first be outlined, which apply to all the panels or to the separate groups of panels.

As previously stated, the number of masonry panels is 22, divided as follows: Nine hollow terra-cotta tile, 6 monolithic concrete, 3 brick, 3 gypsum block, and 1 hollow concrete block. In order to distribute the weight of these panels to best advantage over the different sections of the foundation, the gypsum block panels are placed in the section of the building supported on structural steel—that is, at the south end of the west wall; the brick panels at the north end of the west wall; the monolithic concrete panels in the middle sections of the east wall; and the tile panels in the six middle sections of the west wall, the two south sections of the east wall, and the two north sections of the east wall. The plaster board panels occupy the entire south end of the structure and the back plastered metal lath panels the north end. The metal lath panels of Group I occupy the entire second story on the east wall, except the two north panels, which are of metal lath and belong to Group II. On the second-story west wall the three north panels complete Group II, the next three are of plain wood lath, the next five are of wood lath, counterlathed, and the remaining panel at the south end of the second-story wall is of "Clinton welded sheathing." Finally, the two door panels, which are the third from the south end and the third from the north end on the east side, are of "Bishopric board." This arrangement not only provides solid foundations for the heavier wall sections, but also affords a fairly symmetrical distribution of the various groups.

From the surface of the sheathing to the surface of the finished coat of plaster on the lath panels is nominally 1⅜ inches. On the masonry panels the plaster is ¾ inch thick. In the case of the metal lath panels, the ½-inch furring provides for a coating over the face of the lath approximately ¾ inch thick. In the plain wood lath panels, the furring consists of lath laid vertically over the sheathing paper 12 inches on centers upon which the lath carrying the plaster are nailed horizontally with spacing from ⅜ to ½ inch and with joints broken every twelfth lath. In the

counterlathed panels, the first layer of lath is laid diagonally across the sheathing and directly against the sheathing paper with approximately 1-inch spacing in such manner that a 4-foot lath spans 3 feet horizontally. The outer layer is laid in the same manner but sloped in the opposite direction. As the wood lath is 3/8 inch thick, the nominal thickness of the plaster coating over the outer face of the lath is 5/8 inch. On the plaster board and "Bishopric board" panels the thickness of the plaster coat is from 3/4 to 7/8 inch. The back plastering of the metal lath panels on the north end of the building varies from 1/2 to 3/4 inch thick, although in one case (panel No. 17) this coating was found to be 1 inch thick in places.

In order to observe the manner in which the plaster keys behind the wood and metal lath laid over sheathing, certain cut-outs in the latter between studs were provided which could be removed after the plastering was completed. In order that the lathers should nail into these sections no more than necessary, the positions of the cut-outs were indicated by chalk lines on the sheathing paper, as shown in Fig. 11.

As already outlined, the specifications provide for two-coat work on the plaster board and masonry panels. When the plastering was started it was found that the plasterers were accustomed first to apply a thin scratch coat on such bases, immediately following this with a "laid-on" or "double-up" coat, the latter being later rodded and darbied to a fairly true surface, and finally heavily scratched to receive the finish coat. Thus the chief distinction between two-coat work and three-coat work is that, in the former case, the completion of the plastering requires two days and in the latter three days. Also in the so-called two-coat work performed in this manner, the first coat, consisting of the thin scratch coat and the "double-up" coat, is probably somewhat heavier than the first coat in strictly two-coat work, and similarly, the finish coat is somewhat lighter. However, the method was satisfactory to the inspectors representing the cement and lime interests, and to the local members of the advisory committee, and was adhered to in so far as possible. In a number of cases, especially toward the completion of the plastering with cooler and wet weather, the thin scratch coat did not stiffen rapidly enough, which made it advisable to change from the two-coat work specified to three-coat work. Three coats were also applied over the plaster board and masonry panels coated with bituminous materials, on account

of the lack of absorption of the base and the tendency of the heavy double coat to slide.

The method of finishing the cement panels at the beginning of the work was, first, to lay on the finish coat, and bring to a fairly true surface with darby and float, usually in the forenoon; the coat was then left to stiffen, sometimes for several hours, depending upon circumstances, and finally given a wet float as the final treatment. While this is undoubtedly the practice in most cement finishing and apparently necessary in cornice construction and certain other classes of work, it is nevertheless contrary to the well-recommended practice of avoiding a break of the initial set in the cement, which is probably one of the contributing causes of the unsightly crazing of cement surfaces, especially those exposed to the weather. Accordingly, after conference with representatives of the cement manufacturers' association, it was decided that all panels containing high cement stuccos should be floated to a final finish as soon as possible after laying on the finish coat, even at the sacrifice of evenness and neatness in the finished panel. This change was made on November 5 with some objection from the plasterers, and in some cases at an unnecessary sacrifice in the excellence of the finish. In order to finish in this manner, it was necessary to control the consistency of the plaster more closely. This change, however, affords an opportunity for subsequent comparison of the condition of those cement panels finished in the usual manner and those finished in such manner as to avoid working the cement after the initial set had taken place.

In the erection and plastering of the panels, it was the constant aim of those in charge to carry out every detail of the work to the complete satisfaction of all directly interested in the investigation. To this end, the members of the advisory committee and a number of individual manufacturers were urged to be present and inspect the application of those materials in which they were particularly interested. In general, such inspection was usually provided, the Portland Cement Association and the National Lime Manufacturers' Association having inspectors present during the entire period when the stucco was being applied.

The plastering was done by experienced local plasterers who were recommended by Mr. Earley, of the advisory committee, and furnished by him without compensation other than reimbursement for the plasterers' wages. The mixing was done by hand in small batches usually weighing between 500 and 1000 pounds.

The proportions of the various mixes were under constant inspection and in no case is it probable that there was any considerable departure from the original specifications except in one or two instances noted in the description of the individual panels. The proportions were in all cases determined by weight with the understanding that a bag of cement should be considered 100 pounds n proportioning and that the sand should be weighed as used without regard to its moisture content. The moisture content of the sand was determined from time to time under varying conditions and was found to vary between 5 and 10 per cent with an average value of about 7 per cent.

The hair used in the scratch coats on the lath panels, when not furnished ready mixed with the plastering materials, was the ordinary type of cattle hair obtained in the local market and commonly furnished for this purpose. The hair was first weighed out in small lots as specified in the original program; then the amount required for any particular batch was placed in a sack and the lime was removed by beating with sticks. The hair was thus cleaned and separated, and finally added by hand to the other ingredients in the mixing box. At best, this method is decidedly inferior to machine mixing, but better than the commonly used method of first soaking the hair and then adding it to the mix in small clots.

Some difficulty was experienced in coating the wood lath for panels 20, 24, and 25 with "hydronon." This material is a coal-tar product of the consistency of heavy paint. An attempt was first made to coat the lath with an ordinary paint brush, but the rough surface of the lath made it practically impossible to get a continuous coating. Dipping the lath in the heated compound worked better, but this method required so much material that it was prohibitive. The method finally adopted was to apply the material with a scrub brush; in this manner a fairly satisfactory coating was obtained, but the method can hardly be considered a practicable one.

The "parlock" coating was applied by machinery. The bond material is an asphaltic compound sprayed upon the surface to be coated by means of air at 30 to 40 pounds pressure. This coat is immediately followed by a spray of coarse sand, also applied by an air blast, which adheres to the bituminous material and forms a mechanical bond for the plaster.

The plastering was started October 19 and completed November 24, 1915, with the exception of panels 41 and 56. During the first two weeks of this period, warm and very favorable weather pre-

vailed and the completed plaster coats of the cement stuccos were sprinkled twice daily. After November 3 the weather was noticeably cooler, the drying of the panels was slow, and in view of the possibility of freezing, the sprinkling was discontinued. All plaster coats were wet down with a brush immediately before the next coat was applied, except in a few cases as reported where the plaster was wet. Heavy tarpaulins were frequently used, especially when the work was nearing completion, to protect the freshly plastered coats from rain and frost.

The notes on each panel are so arranged as to give the complete history of the panel with a minimum of reference to other parts of the report. In connection with these notes one may refer to the folded insert at the end, which shows the panel plan of the test structure and gives briefly the construction, base treatment, and stucco formula for each panel. This insert is so arranged that the description of any panel and the panel plan can be examined side by side without turning the pages. Under "weather" are summarized only special weather conditions which might be unfavorable; that is, rain, freezing temperatures, and high winds. Such conditions are noted from the date of application of the first coat until six days after the completion of the panel. Under "superficial inspection" and "detailed inspection" are given the results of the inspection made during the first week of April, 1916.[3] Explanation of the method of examination and system of rating is given in the summarized report on the condition of the test panels, page 58.

GROUP I.

Metal lath on ½-inch crimped galvanized furring, 12 inches apart, over sheathing and sheathing paper. Hair used in first coat. More or less air space between stucco and sheathing.

Panel No. 1

Location: East side, second story, south-end panel.

Construction: 26-gauge galvanized diamond-mesh metal lath, upper half cut from galvanized sheets (sec. a), lower half galvanized after expansion (sec. b), same as panel No. 13. (See Fig. 11.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand), first coat applied afternoon of October 27, second coat afternoon of October 28, finish coat morning of October 29, finished afternoon.

Weather: Moderately gusty wind afternoon of October 30, warm high wind November 2, cold wind November 3, moderate rain and wind November 4, no freezing.

Superficial inspection: Color, light gray, not wholly uniform; structural cracks plainly visible, no other cracking noticeable; surface rough, showing float marks; general appearance fair to good (good to very good except for cracks).

[3] See also remarks on the condition of the panels December 8, 1916, p. 72.

Detailed inspection: Structural and body cracks, no surface cracks; bond good; condition fair.

Remarks: Finished panel photographed November 18 with panel No. 31 (see Fig. 22), showing cracks radiating from window.

Panel No. 2

Location: East side, second story, second panel from south end.

Construction: 24-gauge painted diamond-mesh metal lath, similar to panel No. 13. (See Fig. 11.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand), first coat applied afternoon of October 27, second coat afternoon of October 28, finish coat morning of October 29, finished afternoon.

Weather: Moderately gusty wind afternoon of October 30, warm high wind November 2, cold wind November 3, moderate rain and wind November 4, no freezing.

Superficial inspection: Color, light gray, not wholly uniform; structural cracks plainly visible, no other cracking noticeable; surface rough, showing float marks; general appearance fair to good (good to very good except for cracks).

Detailed inspection: Structural and body cracks, no surface cracks; bond good; condition fair. (Very similar in appearance and condition to panel No. 1.)

Panel No. 3

Location: East side, second story, third panel from south end.

Construction: 24-gauge painted diamond-mesh metal lath, similar to panel No. 13. (See Fig. 11.)

Stucco: B–2 (parts by weight, 0.25 cement, 0.75 high magnesian hydrated lime, 3 sand; second and third coats, 4 parts sand), first coat applied morning of November 6, second coat afternoon of November 8, finish coat 10 a. m. November 15, floated at 1.30 p. m.

Weather: Freezing temperatures recorded November 16, 17, and 18; moderate rain afternoon of November 12, moderate rain throughout day November 14, rain in early morning, gusty northwest wind afternoon of November 15, cold northwest wind November 16, heavy southeast storm night of November 18, showers afternoon of November 19, gusty wind November 21.

Superficial inspection: Color, buff, decidedly nonuniform, blotchy; structural and other prominent cracks visible; float marks somewhat visible; general appearance poor.

Detailed inspection: Structural and body cracks, the latter more vertical than horizontal, some may follow furring; bond good; condition fair.

Panel No. 4

Location: East side, second story, fourth panel from south end.

Construction: 24-gauge painted diamond-mesh metal lath, similar to panel No. 13. (See Fig. 11.)

Stucco: C–1 (parts by weight, 1 "Alca" lime, 3.5 sand; second and third coats 4 part sand), first coat applied morning of October 30, second coat afternoon of November 1, finish coat afternoon of November 3; first coat slightly cracked when second coat was applied.

Weather: Moderately gusty wind afternoon of October 30, warm high wind November 2, cold wind November 3, moderate rain and wind November 4, no freezing.

Superficial inspection: Color, buff to light buff, not wholly uniform; cracks numerous and somewhat visible; float marks somewhat visible; general appearance fair to poor.

Detailed inspection: Structural and body cracks, the latter more vertical than horizontal, some may follow furring; bond good; condition fair. (Condition is very similar to panel No. 3.)

Remarks: Finished panel photographed November 18, after wetting and allowing partially to dry, shows extensive cracking. (See Fig. 9.)

Panel No. 5

Location: East side, second story, fifth panel from south end.

Construction: 24-gauge painted diamond-mesh metal lath, similar to panel No. 13. (See Fig. 11.)

Stucco: D–2 (parts by weight, 1 cement, 2 sand; second and third coats, 3 parts sand), first coat applied morning of November 2, second coat afternoon of November 3, finish coat laid on morning of November 5, dry floated, and finally brushed with a wet whitewash brush, rotary motion, at 3.30 p. m.

Weather: Warm high wind November 2, cold wind November 3, moderate rain and wind November 4, no freezing.

Superficial inspection: Color, medium gray, uniformly mottled; structural cracks and brush marks visible; general appearance good (very good except for cracks).

Detailed inspection: Structural and body cracks, no surface cracks; bond good; condition fair to good. (Condition is similar to panel No. 2, but body cracks are not so wide.)

Panel No. 55

Location: East side, second story, sixth panel from south end.

Construction: 24-gauge painted diamond-mesh metal lath, similar to panel No. 13. (See Fig. 11.)

Stucco: C–2 (parts by weight, 0.75 "Alca" lime, 0.25 cement, 3.5 sand; second and third coats, 4 parts sand), first coat applied afternoon of November 1, second coat morning of November 3, finish coat afternoon of November 4.

Weather: Warm high wind November 2, cold wind November 3, moderate rain and wind November 4, no freezing.

Superficial inspection: Color, light buff, not wholly uniform; structural cracks and float marks somewhat visible; general appearance fair (good except for cracks).

Detailed inspection: Structural and body cracks, the latter vertical at regular intervals over portion of lower part of panel, may follow furring; bond good; condition fair to good.

Panel No. 6

Location: East side, second story, sixth panel from north end.

Construction: 24-gauge painted diamond-mesh metal lath, similar to panel No. 13. (See Fig. 11.)

Stucco: D–3 (parts by weight, 1 cement, 3 sand), first coat applied afternoon of October 29, second coat morning of October 30, finish coat morning of November 1; first coat still wet when second was applied; no water used.

Weather: Moderately gusty wind afternoon of October 30, warm high winds November 2, cold wind November 3, moderate rain and wind November 4; no freezing.

Superficial inspection: Color, medium gray, not wholly uniform on account of spray from cement gun used on panel No. 48 below; structural cracks; float marks somewhat visible; general appearance fair.

Detailed inspection: Structural cracks and one small body crack; bond good; condition good.

Panel No. 7

Location: East side, second story, fifth panel from north end.

Construction: 24-gauge painted diamond-mesh metal lath, similar to panel No. 13. (See Fig. 11.)

Stucco: F–1 (parts by weight, 1 cement, 0.02 "Medusa" waterproofing compound, 3 sand), first coat applied afternoon of November 15, second coat morning of November 18, finish coat morning of November 22; first coat possibly very slightly frozen on surface on morning of November 16.

Weather: Freezing temperatures recorded November 16, 17, 18, 22, 23, 25, and 28, rain in early morning, gusty northwest wind afternoon of November 15, cold northwest wind November 16, heavy southeast storm night of November 18, showers afternoon of November 19, gusty wind November 21, cold northwest wind November 22, panel protected with tarpaulin; rain night of November 23.

Superficial inspection: Color, medium gray, decidedly nonuniform, showing efflorescence on large section of panel; no cracks; surface rough, showing float marks; general appearance fair.

Detailed inspection: Structural cracks and some surface cracks; bond good; condition very good.

Remarks: At the request of the representative of the manufacturer of Medusa waterproofing compound, the finished panel was wet down November 23, 24, 26, 27, 29, and 30. On November 23 water was sprinkled on with a brush and quickly turned to ice on surface of panel. This gradually melted and was absorbed. Soon after the ice formed and before it melted, temperature of the air was observed to be 38° F. Prior to plastering, this panel was open sheathed on interior wall in opposite direction to outside sheathing. This inside bracing was added on panels Nos. 7 and 8, because cracks had been observed on other panels of this group already completed, these cracks developing at upper and lower diagonal corners of windows and running perpendicular to the direction of the sheathing. These cracks were attributed to shrinkage in the sheathing and the bracing was designed to counteract this effect. The fact that the cracks on panels Nos. 7 and 8 are very much smaller in size and number than on similar panels indicates that the cause of the structural cracks is correctly assigned. The waterproofing compound was mixed as follows: A bag of cement was spread upon a tarpaulin and 2 pounds of the compound sprinkled over it. The whole was then mixed to uniform color, sifted twice, and resacked for use as required.

Panel No. 8

Location: East side, second story, fourth panel from north end.

Construction: 24-gauge painted diamond-mesh metal lath, similar to panel No. 13. (See Fig. 11.)

Stucco: F–2 (parts by weight, 1 cement, 0.09 "White Impervite" waterproofing compound, 3 sand), first coat applied morning of November 18, second coat morning of November 19, finish coat morning of November 23, first coat very wet from heavy rain night of November 18 when second coat was applied. The latter was soft when straightened up and scratched afternoon of November 19 and was protected with tarpaulin.

Weather: Freezing temperatures recorded November 18, 22, 23, 25, and 28. Heavy southeast storm night of November 18, showers afternoon of November 19, gusty wind November 21, cold northwest wind November 22, rain at night November 23, cold northwest wind November 29.

Superficial inspection: Color, dark gray, uniform; structural cracks faintly visible; surface rough; general appearance very good.

Detailed inspection: Structural cracks only; bond good; condition excellent.

Remarks: At the request of the manufacturers of Impervite waterproofing compound the finished panel was wet down November 24, 26, 27, 29, and 30. On November 24 the surface was noticeably water repellant, although quite damp when water was applied. Prior to plastering, this panel was open sheathed on the interior wall in opposite direction to outside sheathing. (See remarks under panel No. 7.) This panel after application of first coat is shown at top of Figure 30. The waterproofing was added as follows: Nine pounds of the compound for each bag of cement was thoroughly mixed with water in a bucket. This was added to the other ingredients of the mortar in the mixing box as a part of the mixing water.

Panel No. 9

Location: East side, second story, third panel from north end.

Construction: 20-gauge wire lath, 2½ mesh, galvanized after woven, same as panel No. 12. (See Fig. 10.)

Stucco: A–2 (parts by weight, 0.75 cement, 0.25 high magnesian hydrated lime, 3 sand); first coat applied afternoon of November 2; second coat afternoon of November 4; finish coat laid on 11.15 a. m.; November 5, dry floated, and finally brushed vertically with soft brush 3.30 p. m.; not floated in usual manner. Some air blisters in finish coat were not eliminated.

Weather: Warm high winds November 2; cold wind November 3; moderate rain and wind November 4; no freezing.

Superficial inspection: Color, light buff, badly streaked; furring strips appear to show through; few structural cracks; brush marks slightly visible; general appearance fair (good if not streaked).

Detailed inspection: Structural and surface cracks, vertical and horizontal body cracks; vertical cracks at regular intervals appear to follow furring; at least one horizontal crack follows lap of lath and is apparently fundamental; bond good; condition fair to poor.

Remarks: The lath was so flexible that the original 12-inch spacing of furring was deemed too great, and additional furring was put in, making spacing 6 inches.

GROUP II

Metal lath on ½-inch crimped galvanized furring, 12 inches apart, over sheathing and sheathing paper. No hair used in any coat. Plaster pushed through to thoroughly embed lath.

Panel No. 10

Location: East side, second story, second panel from north end.

Construction: 24-gauge painted diamond-mesh metal lath, similar to panel No. 13. (See Fig. 11.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied afternoon of October 27; second coat afternoon of October 28; finish coat laid on morning of October 29; finished afternoon. First coat was very soft when left on October 27 and was broomed instead of scratched in usual manner.

Weather: Moderately gusty wind afternoon of October 30; warm high wind November 2; cold wind November 3; moderate rain and wind November 4; no freezing.

Superficial inspection: Color, light gray, not wholly uniform; structural and other prominent cracks; surface rough, showing float marks; general appearance fair.

Detailed inspection: Several structural and numerous body cracks; some fundamental cracks apparently following furring; bond good; condition poor.

Panel No. 11

Location: East side, second story, north-end panel.

Construction: 24-gauge painted diamond-mesh metal lath, similar o panel No. 13. (See Fig. 11.)

Stucco: B–2 (parts by weight, 0.25 cement, 0.75 high magnesian hydrated lime, 3 sand; second and third coats 4 parts sand). First coat applied morning of November 6; second coat morning of November 9; finish coat laid on 9 a. m., finished 11 a. m., November 15. Second coat was observed to be badly cracked (mostly horizontal cracks) November 10.

Weather: Freezing temperatures recorded November 16, 17, and 18; moderate rain in afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16; heavy southeast storm night of November 18; showers afternoon of November 19; gusty wind November 21.

Superficial inspection: Color, buff, uniform, shows little efflorescence; structural cracks and float marks somewhat visible; general appearance very good.

Detailed inspection: Structural and body cracks, and probably some fundamental cracks along furring and laps; bond good, condition fair to poor.

Panel No. 12

Location: West side, second story, north-end panel.

Construction: 20-gauge wire lath, 2½ mesh, galvanized after woven. (Shown in Fig. 10.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied afternoon of October 26; second coat morning of October 27; finish coat laid on before noon October 28, finished 4.30 p. m. First coat somewhat too wet for best results, mortar tending to ooze out at bottom of panel when left October 26. This coat required some straightening before application of second. Finish coat was also applied rather wet and was still soft when finished five or six hours after laying on.

Weather: Gusty southeast wind afternoon of October 26, developed into thunder shower 8 p. m.; moderately gusty wind afternoon of October 30; warm high wind November 2; cold wind November 3; no freezing.

Superficial inspection: Color, light gray, uniform; structural cracks; surface rough; general appearance good (very good except for cracks).

Detailed inspection: Some structural cracks; several body cracks at bottom which may align with furring; a few surface cracks; bond good; condition fair to good.

Remarks: Lath was too flexible for the application specified for Group II and additional furring was inserted between the original furring, the final spacing being 6 inches.

Panel No. 13

Location: West side, second story, second panel from north end.

Construction: 26-gauge galvanized diamond-mesh metal lath, upper half cut from galvanized sheets (sec. a), lower half galvanized after expansion (sec. b). (Shown in Fig. 11.)

Stucco: C–1 (parts by weight, 1 "Alca" lime, 3.5 sand; second coat 4 parts sand; finish coat 4 parts limestone screenings). First coat applied afternoon of November 1; second coat morning of November 3; finish coat afternoon of November 4. Panel protected with tarpaulin November 4.

Weather: Warm high winds November 2; cold wind November 3; moderate rain and wind November 4; no freezing.

Superficial inspection: Color, light, nearly white, not wholly uniform; surface covered with prominent cracks, free from float marks; general appearance very poor.

Detailed inspection: Very numerous body cracks a few inches apart, mostly horizontal and vertical, some may follow furring and laps in the lath, bond good; condition very poor.

Panel No. 54

Location: West side, second story, third panel from north end.

Construction: 24-gauge painted diamond-mesh metal lath coated with cement gun. Similar to panel No. 13. (See Fig. 11.) Application of coat shown in Fig. 12.

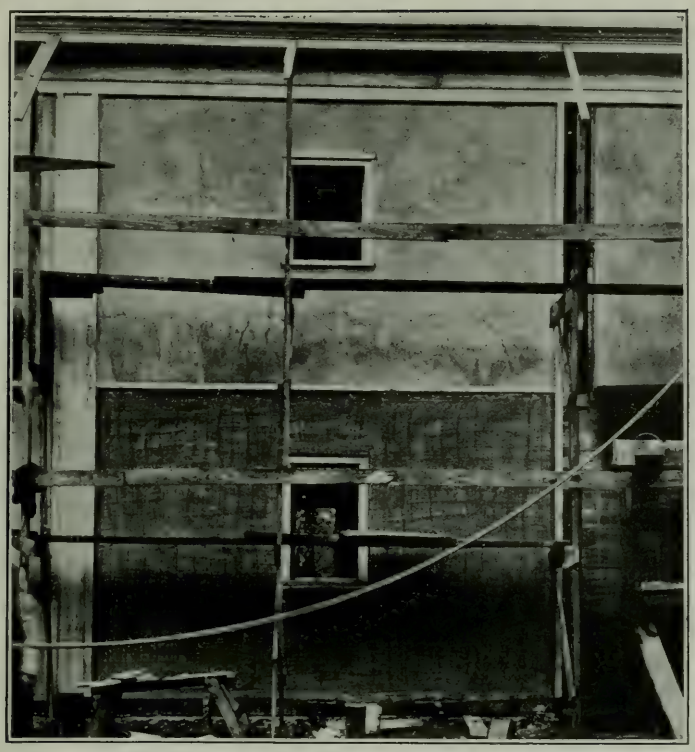

FIG. 9.—*Panel No. 4 (upper) showing extensive body and structural cracks after spraying with water and allowing partially to dry. The photograph was taken November 18, 1915, about two weeks after the plastering of this panel was completed. The lower panel is No. 49, scratch coated only*

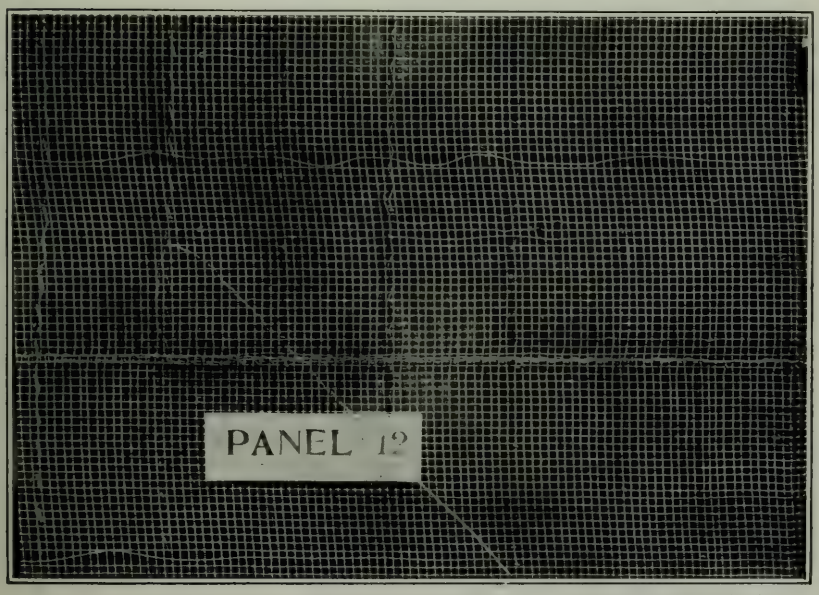

FIG. 10.—*Galvanized woven wire lath on panel No. 12, showing furring 6 inches apart. Same construction on panel No. 9*

FIG. 11.—*Diamond-mesh expanded metal lath on panel No. 13. Similar construction on panels Nos. 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 54, and 55*

FIG. 12.—*Applying cement gun coating on panel No. 54*

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand; see remarks under panel 48, Group X). Stucco applied November 10, rodded and floated by hand. November 11 this panel showed a few horizontal shrinkage cracks in neighborhood of window, which were retouched.

Weather: Freezing temperature recorded November 16; moderate rain in afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15, cold northwest wind November 16.

Superficial inspection: Color, medium gray, not wholly uniform; structural cracks faintly visible, surface rough, general appearance fair to good.

Detailed inspection: Structural cracks only, bond good, condition excellent.

GROUP III

Metal lath on ½-inch crimped galvanized furring attached directly to studs 12 inches apart. No sheathing, lath back plastered on inside between studs. Outer faces of studs coated with "hydronon."

Panel No. 14

Location: North end, second story, east panel.

Construction: 27-gauge painted ribbed metal lath, same as panel No. 16. (See Fig. 13.)

Stucco: G–2 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand; finish coat; 1 white cement, 0.1 high magnesian hydrated lime, 3 limestone screenings). First coat applied morning of November 9, back plastered morning of November 11, second coat afternoon of November 11, finish coat afternoon of November 12. Second coat was fairly hard but quite wet when finish coat was laid on about 2.45 p. m. The latter settled slightly as it was being floated and was still soft when finished at 4.30 p. m.

Weather: Freezing temperatures recorded November 16, 17, and 18. Moderate rain in afternoon of November 12, panel protected with tarpaulin. Moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16.

Superficial inspection: Color, uniform white; no cracks, float marks slightly visible, general appearance excellent.

Detailed inspection: Surface and body cracks only slightly visible, owing to the white-finish cracks practically invisible 10 feet away from panel, bond good; condition very good.

Panel No. 15

Location: North end, second story, west panel.

Construction: 27-gauge painted ribbed metal lath, same as panel No. 16. (See Fig. 13.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied afternoon of October 29, back plastered morning of November 1, second coat morning of November 1, finish coat laid on morning of November 2, finished afternoon. Second coat slid a little at first and was retouched afternoon of November 1. Finish coat of this panel dried rather rapidly in high wind of November 2 and was fairly hard when floated. In consequence, the finished panel has a more sandy appearance than the majority of the A–1 stuccos.

Weather: Moderately gusty wind October 30, warm high winds November 2, cold wind November 3, moderate rain and wind November 4, no freezing.

Superficial inspection: Color, uniform dark gray; no cracks; surface rough, general appearance excellent.

Detailed inspection: No cracks; bond good; condition excellent.

Panel No. 16

Location: North end, first story, east panel.

Construction: 27-gauge painted ribbed metal lath. (Shown in Fig. 13.)

Stucco: B–1 (parts by weight, 0.25 cement, 0.75 high calcium hydrated lime, 3 sand. Second and third coats, 4 parts sand). First coat applied morning of November 9, back plastered afternoon of November 12, second coat afternoon of November 15, finish coat laid on morning of November 18, finished afternoon. Second coat was possibly slightly surface frozen morning of November 16; surface was well broomed before applying finish coat.

Weather: Freezing temperatures recorded November 16, 17, 18, 22, and 23; moderate rain afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16; heavy southeast storm night of November 18; showers afternoon of November 19; gusty winds November 21; cold northwest winds November 22; rain at night November 23.

Superficial inspection: Color, light buff, not wholly uniform; apparent efflorescence to right of window; structural cracks and float marks slightly visible, general appearance good.

Detailed inspection: Several body and structural cracks, at least two fundamental cracks follow studs half the height of panel, some surface cracks; finish coat imperfectly bonded at right of window; condition fair.

Panel No. 17

Location: North end, first story, west panel.

Construction: 20-gauge wire lath, 2½ mesh, galvanized after woven. (Shown in Fig. 14.)

Stucco: E (0.5 cement, 0.5 high nagnesian hydrated lime, 3 sand; second and third coats, 4 parts sand). First coat applied morning of November 4; back plastered afternoon of November 5, second coat morning of November 6, finish coat laid on morning of November 8, finished 1 p. m. Lath so flexible that first coat had to be applied with very little pressure. Back plastering found to be badly cracked November 6, apparently wide shrinkage cracks extending through coat. This coat was probably too heavy and too rich, being of the same proportions as the first coat.

Weather: Moderate rain and wind November 4, moderate rain in afternoon of November 12, moderate rain throughout day November 14, no freezing.

Superficial inspection: Color, uniform light buff, one prominent vertical crack, float marks somewhat visible, general appearance good (very good except for crack).

Detailed inspection: Several surface and structural cracks, some body cracks, at least one fundamental crack over stud; bond good, condition fair.

GROUP IV

Wood lath on ⅜ by 1¼ inch wood furring, 12 inches apart, over sheathing and sheathing paper. Plain lathing, joints broken every twelfth lath. Spacing of lath ⅜ inch.

Panel No. 18

Location: West side, second story, fourth panel from north end.

Construction: Spruce lath, uncoated, similar to panel 20. (See Fig. 15.)

Stucco: A–3 (parts by weight, 1 cement, 0.1 high calcium hydrated lime, 3 sand). First coat applied morning of October 23, second coat morning of October 25, finish coat laid on morning of October 27, finished afternoon. Lath thoroughly wetted about two hours before plastering.

FIG. 13.—*Painted ribbed expanded metal lath on panel No. 16. Same construction on panels Nos. 14 and 15*

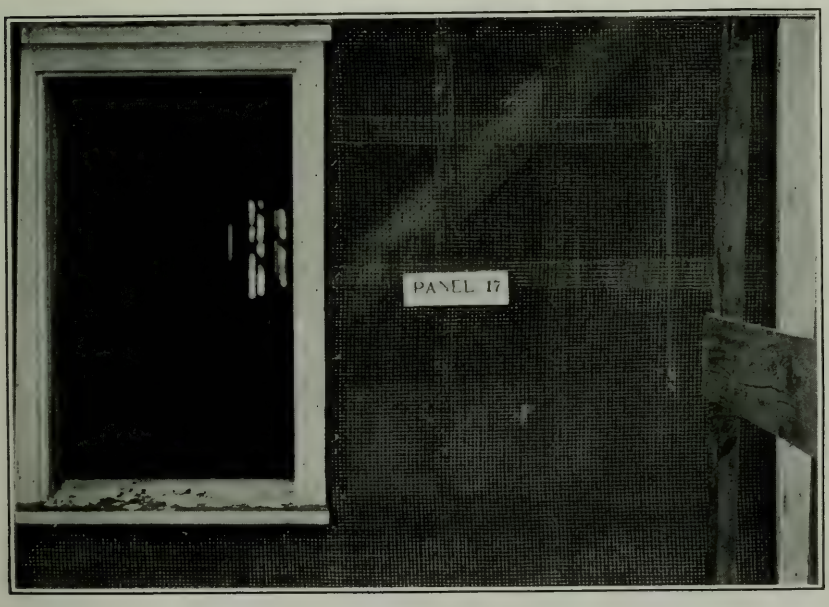

FIG. 14.—*Galvanized woven wire lath on panel No. 17*

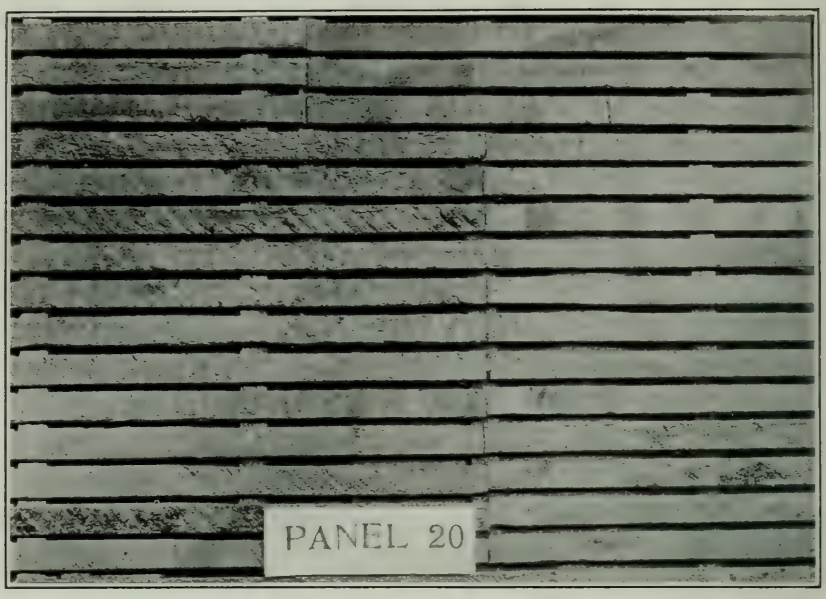

FIG. 15.—*Wood lath, plain lathing, on panel No. 20. Similar construction on panels Nos. 18 and 19*

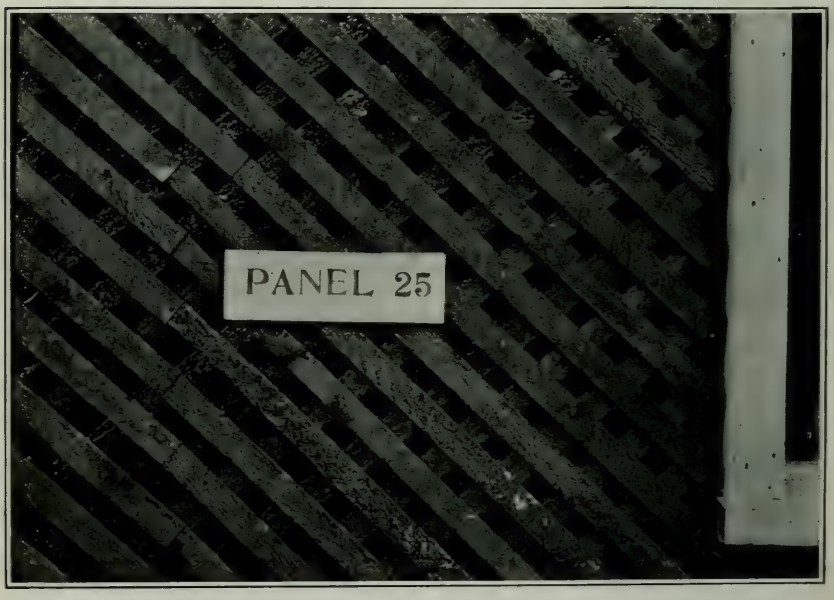

FIG. 16.—*Wood lath, counter lathing, on panel No. 25. Similar construction on panels Nos. 21, 22, 23, and 24*

Weather: Gusty southeast wind afternoon, developed into thunderstorm 8 p. m., October 26; moderately gusty wind afternoon of October 30; warm high wind November 2, no freezing.

Superficial inspection: Color, medium gray, not wholly uniform; structural cracks; surface rough; general appearance good.

Detailed inspection: Structural and a few body cracks; bond good; condition good.

Panel No. 19

Location: West side, second story, fifth panel from north end.

Construction: Spruce lath, uncoated, similar to panel 20. (See Fig. 15.)

Stucco: B–2 (parts by weight, 0.25 cement, 0.75 high magnesian hydrated lime, 3 sand; second and third coats, 4 parts sand). First coat applied morning of November 6, second coat afternoon of November 8, finish coat morning of November 12, finished 11 a. m. Lath thoroughly wetted prior to plastering.

Weather: Freezing temperatures recorded November 16, 17, and 18; moderate rain afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16.

Superficial inspection: Color, buff, not wholly uniform; surface covered with prominent cracks; surface smooth, general appearance very poor.

Detailed inspection: Structural and numerous large body cracks, some of which may be fundamental; bond good; condition poor.

Panel No. 20

Location: West side, second story, sixth panel from north end.

Construction: Spruce lath, coated with "hydronon." (Shown in Fig. 15.)

Stucco: B–2 (parts by weight, 0.25 cement, 0.75 high magnesian hydrated lime, 3 sand; second and third coats, 4 parts sand). First coat applied morning of November 6, second coat afternoon of November 8, finish coat morning of November 12. Lath not wetted before plastering. Second coat had cracked November 9.

Weather: Freezing temperatures recorded November 16, 17, and 18; moderate rain afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16.

Superficial inspection: Color, buff, not wholly uniform; a number of prominent cracks; surface smooth; general appearance fair (good except for cracks).

Detailed inspection: Some structural and numerous large body cracks, some of which may be fundamental; bond good; condition poor.

GROUP V

Wood lath over sheathing and sheathing paper, no furring, counterlathing. Spacing of lath 1 inch. Slope of lath such that the 4-foot lath spans 3 feet horizontally.

Panel No. 21

Location: West side, second story, sixth panel from south end.

Construction: Spruce lath, uncoated, similar to panel No. 25. (See Fig. 16.)

Stucco: A–3 (parts by weight, 1 cement, 0.1 high calcium hydrated lime, 3 sand). First coat applied afternoon of October 22, second coat morning of October 23, finish coat laid on October 27, finished afternoon. Lath thoroughly wetted before plastering. First coat on counterlathing required considerably more material than on plain lathing.

Weather: Gusty southeast wind afternoon, developed into thundershower 8 p. m., October 26; moderately gusty wind afternoon of October 30; warm high wind November 2, no freezing.

Superficial inspection: Color, light gray, not wholly uniform; structural cracks; surface rough; general appearance fair (good except for structural cracks).

Detailed inspection: Structural cracks, possibly one or two small body cracks; bond good; condition very good.

Panel No. 22

Location: West side, second story, fifth panel from south end.

Construction: Spruce lath, uncoated, similar to panel 25. (See Fig. 16.)

Stucco: B–1 (parts by weight, 0.25 cement, 0.75 high calcium hydrated lime, 3 sand; second and third coats, 4 parts sand). First coat applied afternoon of November 2, second coat morning of November 4, finish coat laid on morning of November 5, finished 3 p. m. Suction of first coat very strong; second coat went dry almost immediately, requiring use of darby after covering small area. Lath thoroughly wetted before plastering.

Weather: Warm high winds November 2, cold wind November 3, moderate rain and wind November 4, no freezing.

Superficial inspection: Color, light buff, not wholly uniform, shows pattern of lath over whole panel. Structural and other prominent cracks; float marks slightly visible; general appearance poor.

Detailed inspection: Numerous fundamental and many body cracks, some surface and structural cracks; bond good; condition very poor.

Panel No. 23

Location: West side, second story, fourth panel from south end.

Construction: Spruce lath, uncoated, similar to panel 25. (See Fig. 16.)

Stucco: C–1 (parts by weight, 1 "Alca" lime, 3.5 sand; second and third coats, 4 parts sand). First coat applied morning of October 30, second coat afternoon of November 1, finish coat morning of November 2. First coat extensively and second coat very slightly cracked. Lath thoroughly wetted before plastering.

Weather: Moderately gusty wind afternoon of October 30, warm high winds November 2, cold wind November 3, moderate rain and wind November 4, no freezing.

Superficial inspection: Color, light buff, shows pattern of lath over entire panel, stained by spray from cement gun used on panel 53, below; one structural crack, surface smooth, general appearance fair to poor.

Detailed inspection: Two body cracks and structural cracks around window; bond good; condition very good.

Panel No. 24

Location: West side, second story, third panel from south end.

Construction: Spruce lath, coated with "hydronon," same as panel 25. (See Fig. 16.)

Stucco: A–3 (parts by weight, 1 cement, 0.1 high calcium hydrated lime, 3 sand). First coat applied afternoon of October 22, second coat morning of October 23, finish coat laid on morning of October 26, finished 3.30 p. m. Lath not wetted before plastering.

Weather: Gusty southeast wind afternoon, developed into thundershower 8 p. m., October 26; moderately gusty wind afternoon of October 30, no freezing.

Superficial inspection: Color, dark gray, not wholly uniform; structural cracks and float marks somewhat visible; surface stained with "parlock" spray from panel No. 42 below; general appearance good.

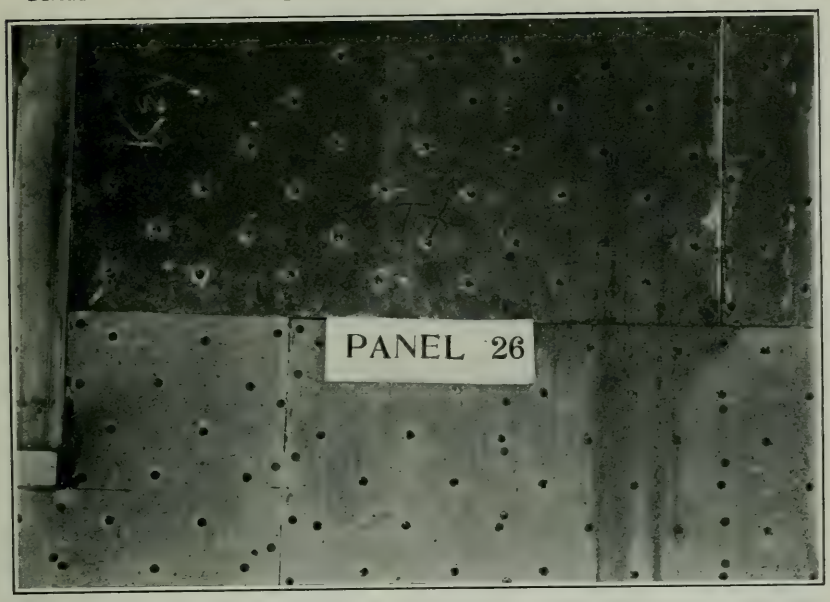

FIG. 17.—*Perforated uncoated plaster board on panel No. 26, felt surfaced board showing above the label, chip surface board below*

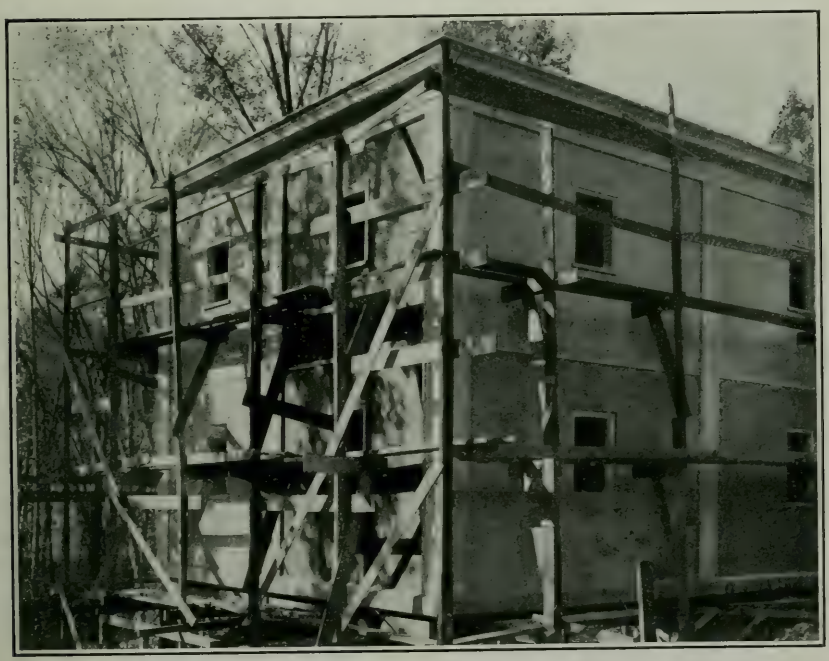

FIG. 18.—*The four plaster board panels on the south end of the test structure, panels Nos. 26 and 27 on the second story, 28 and 29 on first story. The plaster board of panels Nos. 27 and 29 are shown coated with "Parlock" and ready for plastering. Panels Nos. 26 and 28 are already finished*

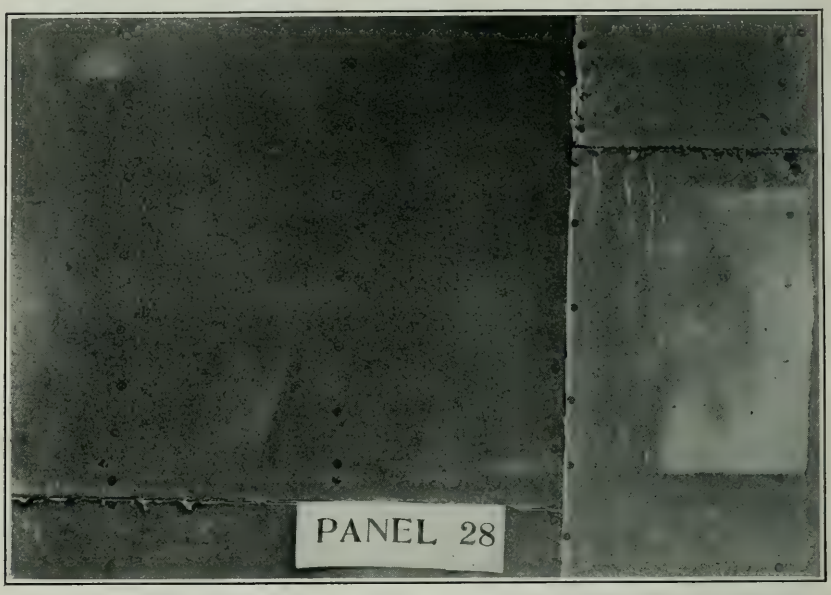

FIG. 19.—*Unperforated uncoated plaster board on panel No. 28. Felt surfaced board at the left, chip surfaced board at the right*

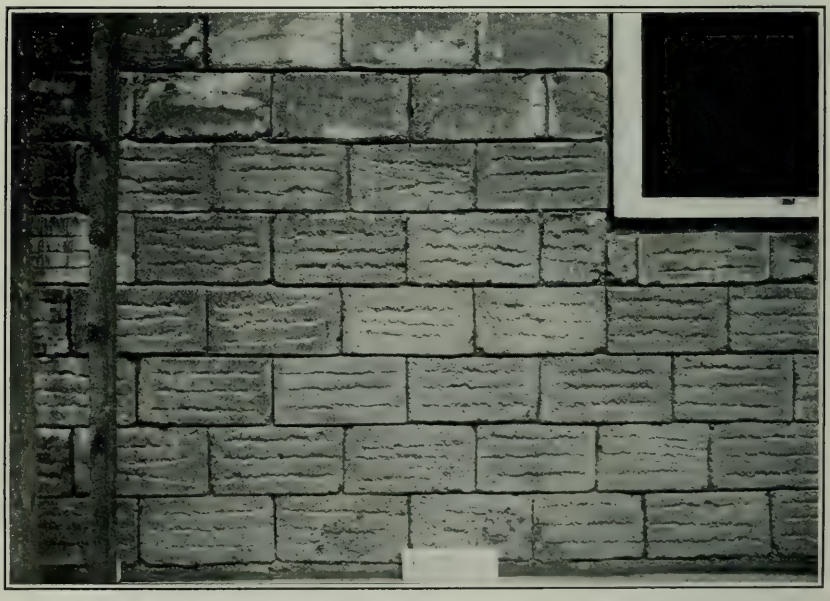

FIG. 20.—*Concrete block panel No. 30, rough block on lower half, smooth block on upper half, two courses of which are shown*

Detailed inspection: Structural cracks, several body cracks from bottom of panel to height of window; bond good; condition good.

Panel No. 25

Location: West side, second story, second panel from south end.

Construction: Spruce lath, coated with "hydronon." (Shown in Fig. 16.)

Stucco: B–1 (parts by weight, 0.25 cement, 0.75 high calcium hydrated lime, 3 sand; second and third coats, 4 parts sand). First coat applied afternoon of November 2, second coat morning of November 4, finish coat laid on 10 a. m., November 5, finished afternoon. Suction of first coat very strong; second coat went dry almost immediately, requiring use of darby after covering small area. Lath not wetted before plastering.

Weather: Warm high winds November 2, cold wind November 3, moderate rain and wind November 4, no freezing. Panel protected with tarpaulin November 4.

Superficial inspection: Color, buff, not wholly uniform; a number of cracks parallel to lath, float marks somewhat visible; general appearance fair.

Detailed inspection: Numerous fundamental and many body cracks; some surface and structural cracks; bond good; condition very poor. (Condition is very similar to panel No. 22.)

GROUP VI

Gypsum plaster board, 3/8 inch thick, nailed directly to studs 12 inches apart. Four-inch spacing of nails, 1/4 inch between boards. (NOTE.—In many places the plaster boards are laid close together or are separated by less than 1/4 inch.)

Panel No. 26

Location: South end, second story, west panel.

Construction: Perforated uncoated plaster board, upper half felt surface (sec. a) lower half chip surface (sec. b). (Shown in Fig. 17.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied afternoon of October 21, second coat morning of October 22, finish coat laid on October 26, finished afternoon. This coat dried more rapidly than usual and has a somewhat sandy finish. There was not time to "double up" the scratch coat on October 21, hence the departure from two-coat work specified in the original program: Plaster board not wetted before plastering.

Weather: Gusty southeast wind afternoon, developed into thunder shower 8 p. m., October 26; moderately gusty wind afternoon of October 30, no freezing.

Superficial inspection: Color, light gray, not wholly uniform; several prominent cracks; float marks somewhat visible; general appearance fair (good except for cracks).

Detailed inspection: A number of fundamental cracks following joints in plaster board, several body cracks diagonally over boards, no surface cracks; bond good; condition poor.

Panel No. 27

Location: South end, second story, east panel.

Construction: Perforated plaster board, upper half felt surface (sec. a) lower half chip surface (sec. b), all coated with "parlock." Panel 27 is shown ready for plastering in Fig. 18.

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied morning of November 11, second coat morning of November 13, finish coat morning of November 16.

Weather: Freezing temperatures recorded November 16, 17, 18, and 22; moderate rain afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16; heavy southeast storm night of November 18; showers afternoon of November 19; gusty wind November 21; cold northwest wind November 22.

Superficial inspection: Color, light gray, not wholly uniform; several prominent cracks; float marks somewhat visible, general appearance fair (good except for cracks).

Detailed inspection: Felt board slightly wrinkled; a number of fundamental cracks following joints in plaster boards, a number of body cracks which appear to follow lines of studs, some running irregularly across boards; a number of surface cracks; bond good; condition poor.

Panel No. 28

Location: South end, first story, west panel.

Construction: Unperforated, uncoated plaster board, left half felt surface (sec. a), right half chip surface (sec. b). (Shown in Fig. 19.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied morning of October 22, immediately "doubled up," finish coat laid on morning of October 26, finished afternoon. The thin scratch coat adhered fairly well, the laid-on coat was apparently too heavy, for the whole cracked and sagged away from the plaster board in spots. Adhesion to the chip surface decidedly better than to the felt surface. The finish coat dried more rapidly than on clay tile or concrete bases and has a somewhat sandy appearance. Plaster board not wetted before plastering.

Weather: Gusty southeast wind afternoon, developed into thunder shower 8 p. m., October 26; moderately gusty wind afternoon of October 30, no freezing.

Superficial inspection: Color, light gray, not wholly uniform; several prominent cracks; float marks somewhat visible; general appearance fair (good except for cracks).

Detailed inspection: Felt-surfaced plaster board appeared to be considerably wrinkled in some cases, board cracked in one place. These wrinkles also found in the original board. Chip board in good condition. A number of fundamental cracks at joints, body and surface cracks; bond good; condition poor.

Panel No. 29

Location: South end, first story, east panel.

Construction: Unperforated plaster board, upper half felt surface (sec. a), lower half chip surface (sec. b), all coated with "parlock." Panel 29 ready for plastering is shown in Fig. 18.

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied morning of November 11, second coat morning of November 13, finish coat morning of November 16. "Parlock" coat is of irregular thickness, very heavy in spots, caused by rapid drying in sun when applied.

Weather: Freezing temperatures recorded November 16, 17, 18, and 22; moderate rain afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16; heavy southeast storm night of November 18, showers afternoon of November 19; gusty wind November 21; cold northwest wind November 22.

Superficial inspection: Color, light gray, not wholly uniform; several prominent cracks; float marks somewhat visible; general appearance fair (good except for cracks).

Detailed inspection: Felt board very slightly wrinkled; a number of fundamental cracks at joints, body cracks, some running diagonally across boards, and surface cracks; bond good; condition poor.

Remarks: Panels Nos. 26, 27, 28, and 29 are very similar in appearance and condition.

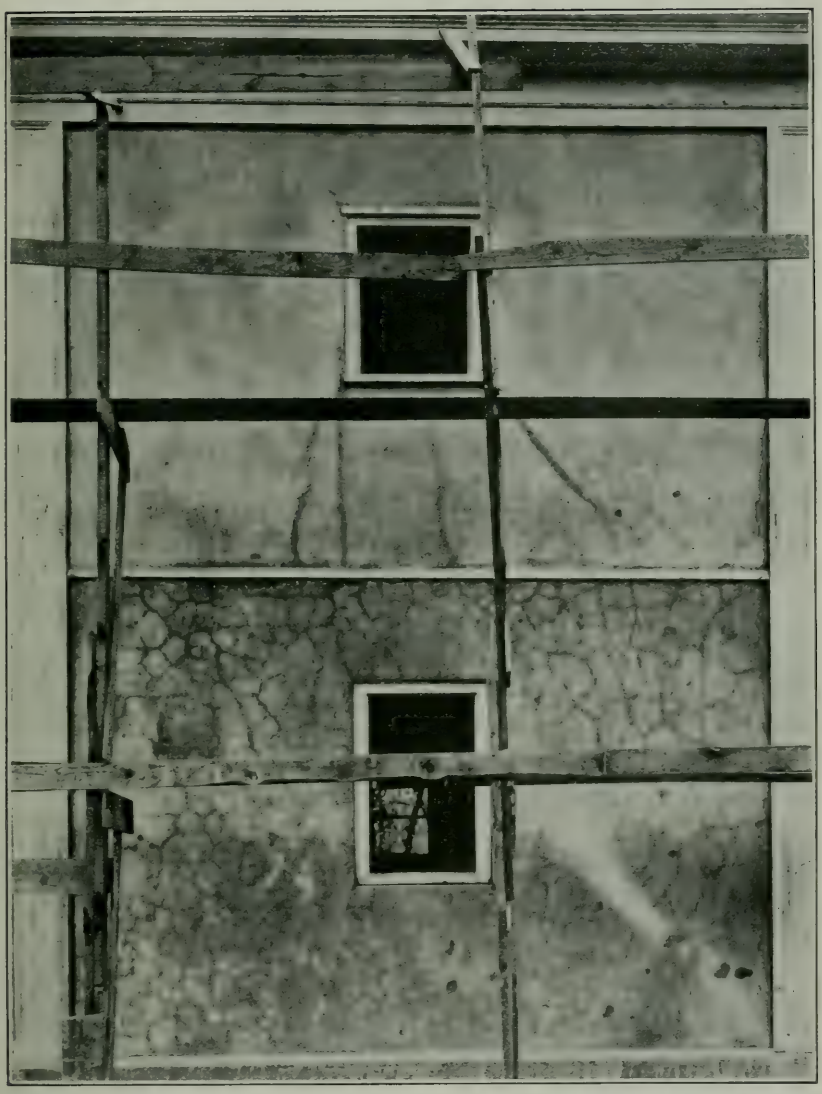

FIG. 22.—*Map cracking (body cracks) on panel No. 31 (lower) and structural cracks on panel No. 1 (upper), after spraying with water and allowing partially to dry. This photograph was taken November 18, about three weeks after the plastering of these panels was completed*

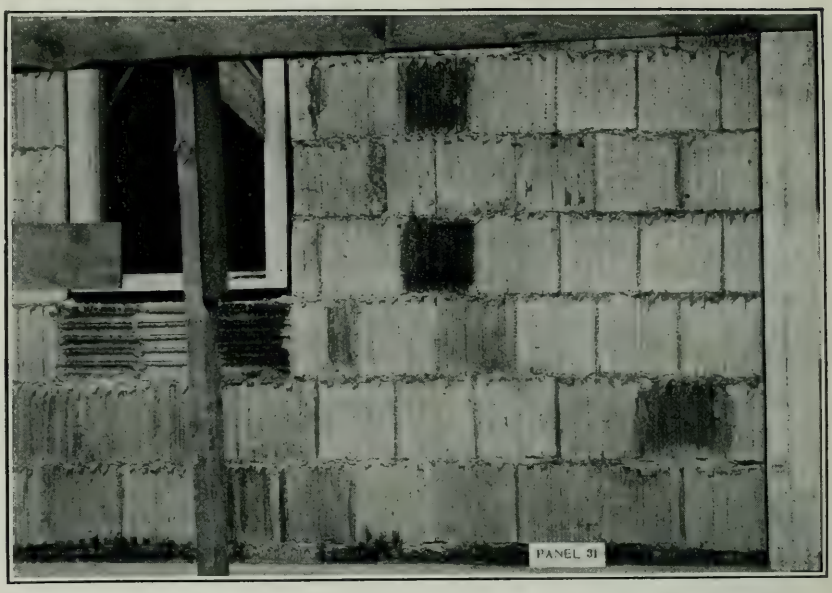

FIG. 21.—*Hollow terra cotta tile of panel No. 31. Same construction in panels Nos. 32, 33, 34, and 53*

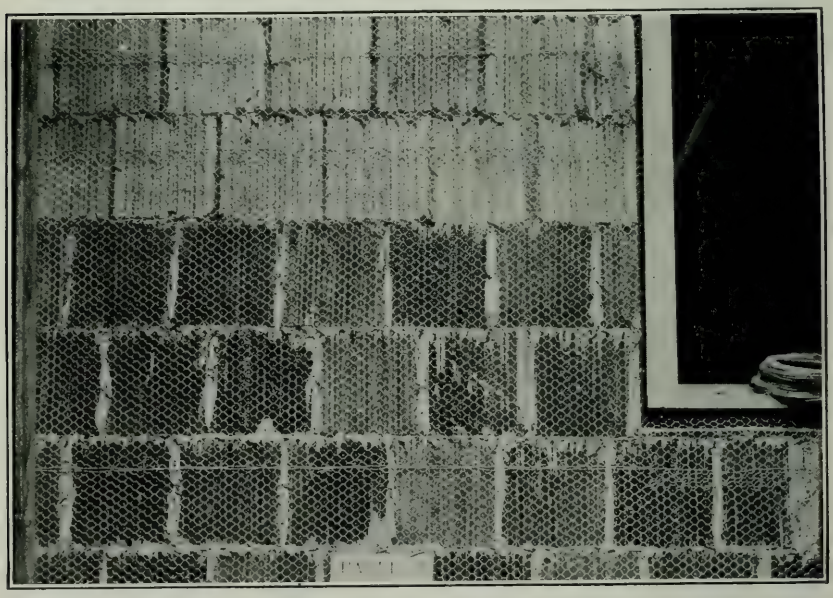

FIG. 23.—*Galvanized wire mesh over hollow terra cotta tile of panel No. 35. The dark colored tiles on the lower half are glazed*

GROUP VII

Glazed and unglazed hollow terra-cotta tile and concrete block. Terra-cotta tile hard burned, with dovetail ragged scoring.

Panel No. 30

Location: West side, first story, fourth panel from north end.

Construction: Hollow concrete block, upper half smooth block (sec. a), lower half rough block (sec. b). (Shown in Fig. 20.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied October 19, second coat October 20, finish coat laid on afternoon October 25, finished 5.30 p. m. First coat too wet to support laid-on coat October 19, hence panel was given three coats instead of two as originally specified. Left half of this panel wetted, right half wetted and brushed with neat cement grout immediately before plastering.

Weather: Heavy rain early morning October 20; gusty southeast wind afternoon developed into thundershower 8 p. m., October 26; moderately gusty wind afternoon of October 30, no freezing.

Superficial inspection: Color, light gray, several large discolored patches; one crack slightly, and float marks somewhat, visible; general appearance fair (good except for blotches).

Detailed inspection: Numerous surface cracks all over panel; numerous body cracks; one vertical crack may be structural; bond good; condition fair.

Panel No. 31

Location: East side, first story, south-end panel.

Construction: Hollow terra-cotta tile. (Shown in Fig. 21.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand, upper half of haired plaster (sec. a), lower half without hair (sec. b)). First coat applied afternoon of October 20, and immediately "doubled up." Some tendency of plaster to slide on section b apparently due more to use of wetter mix on lower half than to absence of hair. On October 21 this coat was retouched and straightened. Finish coat laid on morning of October 25, finished afternoon. Tile thoroughly wetted before plastering.

Weather: Heavy rain early morning October 20; gusty southeast wind afternoon developed into thundershower 8 p. m., October 26; moderately gusty wind afternoon of October 30, no freezing.

Superficial inspection: Color, light gray, not wholly uniform; no cracks visible; float marks slightly visible, general appearance good.

Detailed inspection: Surface and body cracks running in all directions cover entire panel a few inches apart; no fundamental nor structural cracks; bond good; condition fair to poor.

Remarks: Fig. 22 is a photograph of this panel showing typical "map cracking"; taken November 18 after wetting the panel and allowing partially to dry.

Panel No. 32

Location: East side, first story, second panel from south end.

Construction: Hollow terra-cotta tile, same as panel No. 31. (See Fig. 21.)

Stucco: B–1 (parts by weight, 0.25 cement, 0.75 high calcium hydrated lime, 3 sand; second coat 4 parts sand). First coat applied November 9 and immediately "doubled up." November 10 this coat was found to be badly cracked and was gone over with wet float and rescratched. Finish coat laid on morning of November 17, finished afternoon. Tile thoroughly wetted before plastering.

Weather: Freezing temperatures recorded November 16, 17, 18, 22, and 23; moderate rain in afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16; heavy southeast storm night of November 18; showers afternoon of November 19; gusty wind November 21; cold northwest wind November 22; rain at night November 23.

Superficial inspection: Color, light buff, not wholly uniform, cracks somewhat visible; surface contains a number of blisters and scaly patches; general appearance poor.

Detailed inspection: Surface covered with body cracks running in all directions a few inches apart; some surface cracks; bond poor, outside coat appears to be loose and scaling in many places; condition very poor.

Panel No. 33

Location: East side, first story, second panel from north end.

Construction: Hollow terra-cotta tile, same as panel No. 31. (See Fig. 21.)

Stucco: C–1 (parts by weight, 1 "Alca" lime, 4 sand; this mixture used in both coats on manufacturers' recommendation). First coat applied November 3, about noon, immediately "doubled up," and finally straightened and scratched about 4 p. m. Finish coat applied morning of November 8. Tile thoroughly wetted before plastering.

Weather: Cold wind November 3, moderate rain and wind November 4, moderate rain afternoon of November 12, moderate rain throughout day November 14, no freezing.

Superficial inspection: Color, light buff, distinctly nonuniform; surface smooth but covered with prominent cracks; general appearance very poor.

Detailed inspection: Numerous body cracks running irregularly over surface of panel a few inches apart; bond good; condition poor.

Panel No. 34

Location: East side, first story, north-end panel.

Construction: Hollow terra-cotta tile, same as panel No. 31. (See Fig. 21.)

Stucco: D–1 (parts by weight, 1 cement, 2.5 sand). First coat applied afternoon of November 18, second coat morning of November 19, finish coat afternoon of November 22. First coat was very wet from heavy rain preceding night when second coat was applied. The latter was soft when straightened and scratched. Tile thoroughly wetted before plastering.

Weather: Freezing temperatures recorded November 18, 22, 23, 25, and 28; heavy southeast storm night of November 18, showers afternoon of November 19, panel protected with tarpaulin, gusty wind November 21; cold northwest wind November 22, panel protected with tarpaulin; rain at night November 23.

Superficial inspection: Color, dark gray, slightly blotchy; no cracks; surface rough; general appearance fair (good except for nonuniform color).

Detailed inspection: Body cracks slightly visible; stucco appears to have separated in spots but no blistering, cracking, or scaling noted; condition good.

Panel No. 35

Location: West side, first story, fifth panel from north end.

Construction: Hollow terra-cotta tile, upper half unglazed tile (sec. a), lower half glazed tile (sec. b), all covered with ¾-inch galvanized-wire mesh. (Shown in Fig. 23.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied morning of October 19, immediately "doubled up" and allowed to

stand until afternoon before straightening and scratching. This coat was rescratched October 20 to improve mechanical bond for finish coat. Finish coat laid on afternoon October 25, finished 4.30 p. m., somewhat too wet to finish nicely. Tile thoroughly wetted before plastering.

Weather: Heavy rain early morning October 20; gusty southeast wind afternoon developed into thundershower 8 p. m. October 26; moderately gusty wind afternoon of October 30, no freezing.

Superficial inspection: Color, light gray, nonuniform, one large discolored patch; several cracks somewhat visible, float marks slightly visible; general appearance poor (fair except for discolored patches).

Detailed inspection: Numerous body cracks several inches apart; no structural nor fundamental cracks, some surface cracks; no difference noted between sections a and b; bond good; condition fair to poor.

Panel No. 36

Location: West side, first story, sixth panel from north end.

Construction: Hollow terra-cotta tile, upper half uncoated (sec. a), lower left quarter coated with "parlock" (sec. b), lower right quarter coated with "hydronon" (sec. c). (Shown in Fig. 24.)

Stucco: A–2 (parts by weight, 0.75 cement, 0.25 high magnesian hydrated lime, 3 sand). First coat applied morning of November 10, second coat afternoon of November 15, finish coat afternoon of November 17. Vertical shrinkage cracks noted November 11 in first coat on sections b and c. Second coat possibly slightly surface frozen night of November 15. Bituminous coats extend 21 inches above window sill. Upper half of base well wetted prior to plastering.

Weather: Freezing temperatures recorded November 16, 17, 18, 22, and 23; moderate rain afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16; heavy southeast storm night of November 18; showers afternoon of November 19; gusty wind November 21; cold northwest wind November 22, rain at night November 23.

Superficial inspection: Color, light gray, nonuniform. Several prominent cracks; float marks somewhat visible; left half shows large amount of efflorescence, especially on section b; general appearance fair.

Detailed inspection: Numerous surface and body cracks several inches apart on sections b and c, only surface cracks on section a; bond good; condition, section a, good; sections b and c, poor.

Panel No. 37

Location: West side, first story, sixth panel from south end.

Construction: Hollow terra-cotta tile, upper half uncoated (sec. a), lower left quarter coated with "parlock" (sec. b), lower right quarter coated with "antihydrine" (sec. c). (See Fig. 24.)

Stucco: G–1 (parts by weight, 1 cement, 0.3 high magnesian hydrated lime, 3 sand; finish coat, 1 white cement, 0.1 high magnesian hydrated lime, 2 white silica sand). First coat applied November 9, second coat afternoon of November 11, finish coat afternoon of November 17. Vertical shrinkage cracks in first coat noted November 11, rather more on this panel than on panels No. 36 and No. 38. November 12 second coat appeared to have separated in spots from first coat and cracked considerably. Bituminous coats extend 21 inches above window sill. Tile of section a thoroughly wetted prior to plastering.

Weather: Freezing temperatures recorded November 16, 17, 18, 22, and 23; moderate rain afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold north-

west wind November 16; heavy southeast storm night of November 18; showers afternoon of November 19; gusty wind November 21; cold northwest wind November 22; rain at night November 23.

Superficial inspection: Color, uniform white; no cracks; surface even; general appearance excellent.

Detailed inspection: Sections b and c show a number of body cracks 8 to 10 inches apart, section a two or three cracks a few inches long; bond good; condition, section a, excellent; section b, fair to good; section c, fair.

Panel No. 38

Location: West side, first story, fifth panel from south end.

Construction: Glazed terra-cotta tile, upper half uncoated (sec. a), lower left quarter coated with "parlock" (sec. b), lower right quarter coated with "antihydrine" (sec. c). (Shown in Fig. 24.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied morning of November 10, second coat morning of November 13, finish coat morning of November 17. Vertical shrinkage cracks noted in first coat November 11. Bituminous coats extend 21 inches above window sill. Base not wetted before plastering.

Weather: Freezing temperatures recorded November 16, 17, 18, 22, and 23; moderate rain afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16; heavy southeast storm night of November 18; showers afternoon of November 19; gusty wind November 21; cold northwest wind November 22; rain at night November 23.

Superficial inspection: Color, dark gray, uniform except for efflorescence (mostly on sec. c); no cracks; surface rough, especially on section a; general appearance fair (very good except for efflorescence).

Detailed inspection: Several body cracks on sections b and c, no cracks on section a; bond good; condition, section a, excellent; sections b and c, fair.

Panel No. 53

Location: West side, first story, fourth panel from south end.

Construction: Hollow terra-cotta tile, coated with cement gum, same as panel No. 31. (See Fig. 21.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand. See notes under Panel 48, Group X). Coating applied November 10, rodded and floated by hand. The panel is poorly finished, owing to darkness coming on before work was completed. Some shrinkage cracks were observed November 11, and retouched. Tile thoroughly wetted before coating was applied.

Weather: Freezing temperature recorded November 16; moderate rain in afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16.

Superficial inspection: Color, dark gray, nonuniform, splotchy; two slightly visible cracks, float marks somewhat visible; general appearance poor.

Detailed inspection: Numerous surface cracks 8 to 10 inches apart covering entire panel, and a number of body cracks; bond good; condition fair.

GROUP VIII

Brick, common rough, hard burned. Where stucco is applied directly to brick, mortar joints are raked out to depth of $\frac{3}{8}$ or $\frac{1}{2}$ inch.

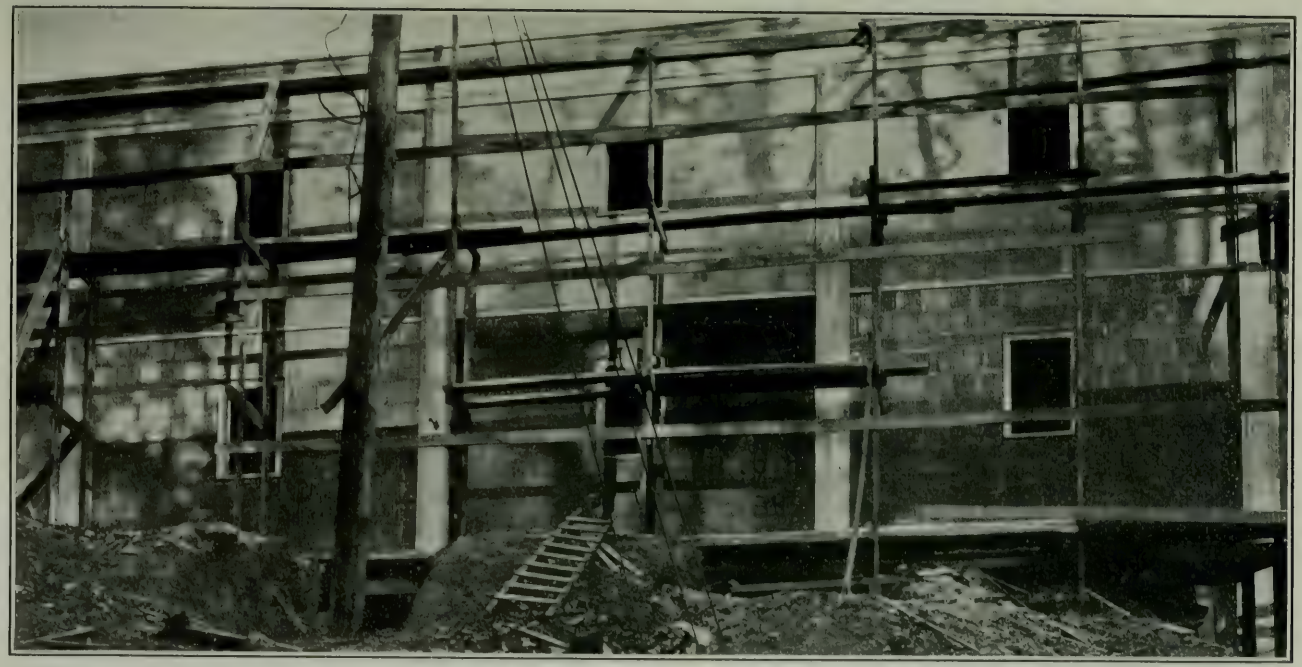

FIG. 24.—*Panels Nos. 36 and 38 ready for plastering are the lower left and lower right panels, respectively. The lower half of each is coated with bituminous material. Panel No. 37 (center) has already been scratch coated and is of the same construction and base treatment as panel No. 36*

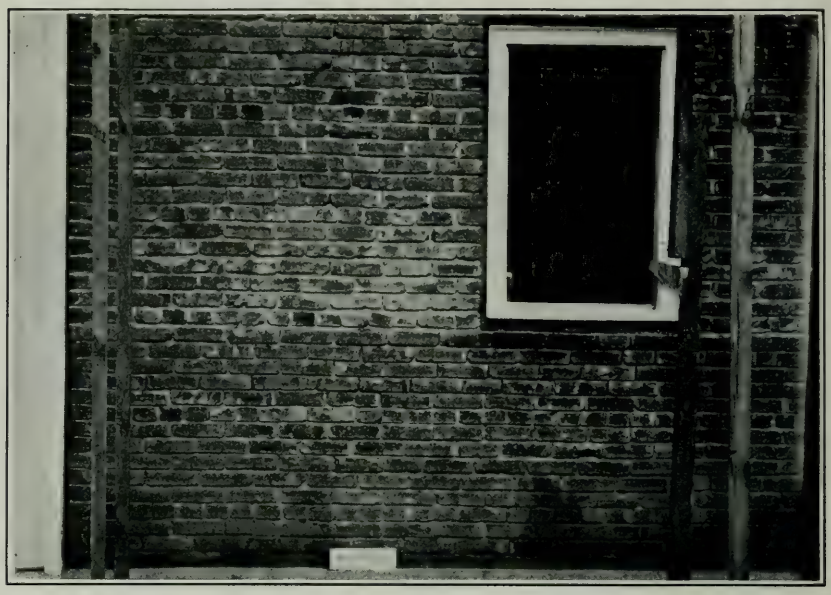

FIG. 25.—*Brick of panel No. 39. Same construction in panel No. 40*

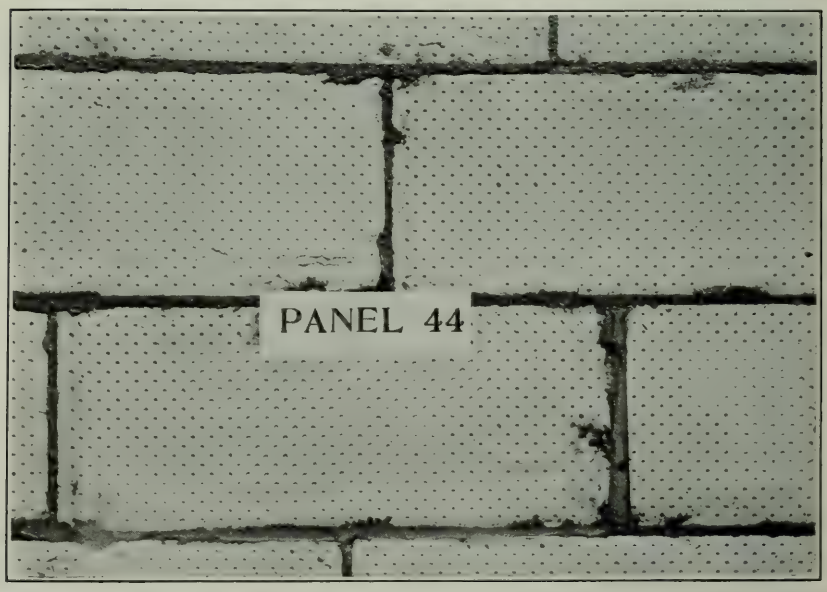

FIG. 27.—*Corrugated gypsum block of panel No. 44*

Panel No. 39

Location: West side, first story, north end panel.

Construction: Rough hard brick. (Shown in Fig. 25.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied October 21 and immediately "doubled up." Upper half of haired mortar (sec. a), lower half without hair (sec. b). Finish coat laid on morning of October 28, almost too wet to finish at 4.30 p. m. Brick thoroughly wetted before plastering.

Weather: Gusty southeast wind afternoon, developed into thunder shower 8 p. m., October 26; moderately gusty wind afternoon of October 30, warm high wind November 2; cold wind November 3; no freezing.

Superficial inspection: Color, light gray, showing a few prominent discolored spots; no cracks; float marks slightly visible; general appearance fair (good except for spots).

Detailed inspection: Surface cracks an inch or two apart all over panel; bond good; no difference noted in sections a and b; condition very good.

Panel No. 40

Location: West side, first story, second panel from north end.

Construction: Rough hard brick, same as panel 39. (See Fig. 25.)

Stucco: B–2 (parts by weight, 0.25 cement, 0.75 high magnesian hydrated lime, 4 sand. These proportions used throughout on this panel). First coat applied November 10, immediately "doubled up"; finish coat laid on morning of November 16, temperature about freezing. Plaster did not freeze but remained very soft and was not finally floated until 4 p. m. Panel was protected with tarpaulin night of November 16.

Weather: Freezing temperatures recorded November 16, 17, 18, and 22; moderate rain afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16; heavy southeast storm night of November 18; showers afternoon of November 19; gusty wind November 21; cold northwest wind November 22.

Superficial inspection: Color, buff, nonuniform, no cracks nor float marks; general appearance, fair.

Detailed inspection: Numerous surface cracks several inches apart covering entire panel; several body cracks; bond just above water table seems to be affected by dampness, mortar softened and flaking; condition fair to good.

Panel No. 41

Location: West side, first story, third panel from north end.

Construction: Brick, with struck joints; that is, mortar finished flush with face of brick.

Remarks: This panel was to be painted to simulate an old wall, stucco to be keyed with two bituminous materials. Panel did not dry sufficiently before cold weather to warrant painting and is unfinished at the present time.

GROUP IX

Gypsum block, smooth and corrugated.

Panel No. 42

Location: West side, first story, third panel from south end.

Construction: Smooth gypsum block, coated with "parlock." (Shown in Fig. 26.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied morning of November 10, second coat afternoon of November 12, finish coat afternoon of November 16. Second coat very soft when finally straightened

at close of work November 12, and showed some tendency to bag. This coat showed patches of efflorescence November 16.

Weather: Freezing temperatures recorded November 16, 17, 18, and 22; moderate rain in afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16, panel was protected with tarpaulin; heavy southeast storm night of November 18; showers afternoon of November 19; gusty wind November 21; cold northwest wind November 22.

Superficial inspection: Color, dark gray, uniform except for efflorescence; two prominent cracks; float marks slightly visible; general appearance fair to poor.

Detailed inspection: Some surface cracking—one crack appears to be a deep body crack, but may be fundamental; bond good; condition good.

Remarks: "Parlock" was applied October 27. Gypsum block were protected from rain October 26 by tarpaulins.

Panel No. 43

Location: West side, first story, second panel from south end.

Construction: Corrugated gypsum block, coated with "parlock." (Shown in Fig. 26.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied November 9, second coat morning of November 11, finish coat afternoon of November 16.

Weather: Freezing temperatures recorded November 16, 17, 18, and 22; moderate rain afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16, panel protected with tarpaulin; heavy southeast storm night of November 18; showers afternoon of November 19; gusty wind November 21; cold northwest wind November 22.

Superficial inspection: Color, dark gray, uniform except for efflorescence; two prominent cracks; float marks slightly visible; general appearance fair.

Detailed inspection: Two large cracks, may be either body or fundamental; bond good, except possibly at lower right corner; condition good.

Remarks: "Parlock" was applied October 27. Gypsum block were protected from rain October 26 by tarpaulin.

Panel No. 44

Location: West side, first story, south-end panel.

Construction: Uncoated corrugated gypsum block. (Shown in Fig. 27.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied October 21. At the request of the gypsum manufacturers, the lower half of this panel was scratch coated with 1:2 gypsum plaster (sec. b), the upper half with stucco A–1 (sec. a). Prior to application of scratch coat, base was slightly wetted through a misunderstanding of instructions. Water was quickly absorbed from first coat, which was immediately "doubled up." Finish coat laid on morning of October 26; finished afternoon. This coat dried rapidly and has a sandy appearance.

Weather: Gusty southeast wind afternoon, developed into thunder shower 8 p. m., October 26: moderately gusty wind afternoon of October 30, no freezing.

Superficial inspection: Color, section a, medium gray, nonuniform: section b, uniform dark gray; three prominent cracks; surface smooth; general appearance: Section a, poor; section b, fair to good.

Detailed inspection: Possibly one or two structural cracks, numerous body cracks, especially on section b, bond poor in numerous places on both sections; condition: Section a, poor; section b, very poor.

Remarks: On October 22 and the following days the scratch coat on section a was sprinkled twice daily with whisk broom, the entire finish coat was sprayed regularly after October 27. Section a extends 4½ feet from top of panel.

FIG. 26.—*Panels Nos. 42 and 43 (first story) of smooth and corrugated gypsum block, respectively, coated with "Parlock" and ready for plastering*

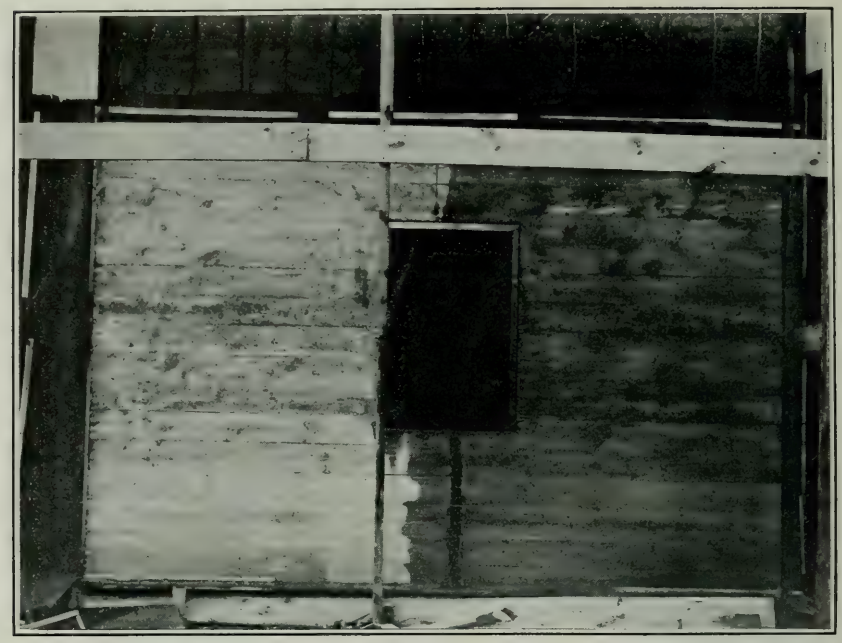

FIG. 28.—*Concrete base of panel No. 45, showing right half saturated with water just before "Parlock" coating was applied*

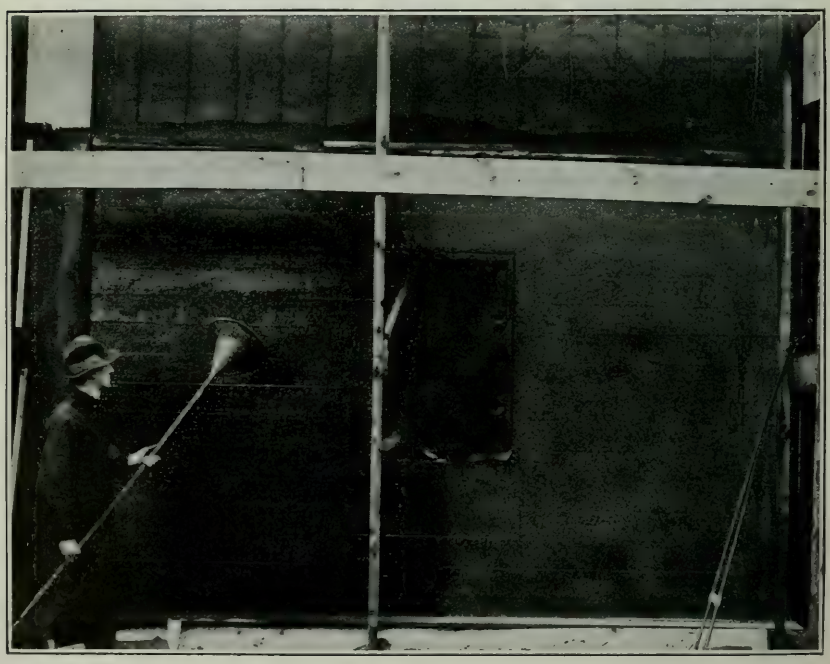

FIG. 29.—*Completing the application of "Parlock" on panel No. 45 with sand-spraying nozzle*

GROUP X

Monolithic Concrete. Of the six panels in this group, three were poured as the first-story walls were being erected, 9 or 10 weeks before plastering, and three were poured after the remainder of the structure was completed, 2 days before plastering. The concrete is 8 inches thick and composed of 1 part Portland cement, 2 parts sand and 4 parts gravel. The surfaces were generally smooth and free from pockets, except in the upper sections of the three last poured, where the construction did not permit of thorough spading.

Panel No. 45

Location: East side, first story, fifth panel from north end.

Construction: Monolithic concrete, poured September 14, coated with "parlock" October 26; right half of panel wetted at intervals for an hour or more previous to application of "parlock." (Shown in Fig. 28.) Figure 29 shows operator completing application of "parlock."

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied afternoon of November 18. This coat partially washed off by rain during night of November 18; remainder was removed with hose, and first coat reapplied morning of November 19; second coat afternoon of November 22; finish coat aid on 9 a. m. November 24; finished, when still soft, at 3 p. m. Mix for this coat appeared to be too wet for best results in finishing.

Weather: Freezing temperatures recorded November 22, 23, 25, 28, and 30; showers afternoon of November 19; gusty wind November 21; cold northwest wind November 22, panel protected with tarpaulin; rain at night November 23; cold northwest wind November 29.

Superficial inspection: Color, light gray, somewhat streaked; no cracks; surface rough and somewhat wavy; general appearance fair to good.

Detailed inspection: Numerous very fine body cracks, and numerous surface cracks running in all directions close together; bond good; condition fair.

Panel No. 46

Location: East side, first story, sixth panel from south end.

Construction: Monolithic concrete poured November 20, plastered soon after removal of forms. Base divided into four vertical sections: left section (a) untreated, second section (b) grouted only, third section (c) wire brushed only, right section (d) wire brushed and grouted.

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied afternoon of November 22, second coat morning of November 23, finish coat laid on 10 a. m., November 24, finished 1 p. m. Plaster for this coat appeared to be too wet for best results in finishing.

Weather: Freezing temperatures recorded November 22, 23, 25, 28, and 30, cold northwest wind November 22, panel protected with tarpaulin; rain at night November 23; cold northwest wind November 29.

Superficial inspection: Color, dark gray, nonuniform; no cracks, surface rough, general appearance fair.

Detailed inspection: Surface cracks slightly visible over entire surface, one small body crack; bond good; condition very good.

Remarks: Forms removed and base treatment given prior to plastering November 22. Sections a and d are each 3 feet 6 inches wide; sections b and c each 4 feet 1 inch wide.

Panel No. 47

Location: East side, first story, fourth panel from north end.

Construction: Monolithic concrete, poured September 13; base divided into three vertical sections: left section (a) scrubbed with 1:4 muriatic acid (7.3 per cent solution by weight); middle section (b) roughened with stone pick; right section (c) scrubbed with acetic acid (12 per cent solution by weight). (Shown in Fig. 30.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied afternoon of November 18; partially washed off by heavy rain night of November 18; remainder was scraped off, the base wire brushed, hosed, and replastered morning of November 19. Acid treatment not repeated before replastering. Second coat applied afternoon of November 22, finish coat afternoon of November 23.

Weather: Freezing temperatures recorded November 22, 23, 25, and 28; showers afternoon of November 19, panel protected with tarpaulin; rain at night November 23; cold northwest wind November 29.

Superficial inspection: Color, uniform medium gray, slightly streaked and spotted; no cracks nor float marks; surface slightly wavy; appearance good.

Detailed inspection: Surface cracks and one small blister noted; bond good; condition very good.

Remarks: The tooled portion of the base is 6 feet 2 inches wide, the acid-treated portions each 4 feet wide. Acid treatment did not expose aggregate in either case, but simply cleaned the surface. Action of acetic acid very slight as compared with that of muriatic acid.

Panel No. 48

Location: East side, first story, sixth panel from north end.

Construction: Monolithic concrete, poured September 15, smooth, untreated except wetting prior to coating with cement gun. Base of this panel similar to panel No. 45 before "parlock" treatment. (See Fig. 28.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). Applied November 10, rodded and floated by hand. On November 11 the panel showed one shrinkage crack about 6 inches long near bottom.

Weather: Freezing temperatures recorded November 16; moderate rain in afternoon of November 12; moderate rain throughout day November 14; rain in early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16.

Superficial inspection: Color, dark gray, not wholly uniform, no cracks; float marks somewhat visible; general appearance very good.

Detailed inspection: Numerous surface cracks, particularly in lower section; bond good; condition very good.

Remarks: An attempt to "shoot" the returns at the windows of the gun-coated panels was not successful; these were finished by hand November 11. According to statement of the Cement Gun Co., the rebound of sand during application gives a coating in which the proportion of sand is about 2⅝ instead of 3, as used in the original mixture. The coating appears very dense but is not entirely uniform. This may be due to lack of an adequate air supply, which required the use of a smaller operating nozzle than is ordinarily employed.

Panel No. 49

Location: East side, first story, fourth panel from south end.

Construction: Monolithic concrete, poured November 16, forms removed and base treatment given prior to plastering November 18. Left half untreated (sec. a), right half wire brushed (sec. b). (Shown in Fig. 31. After this photograph was taken the smoother portions on right half were rebrushed.)

Stucco: C–1 (parts by weight, 1 "Alca" lime, 4 sand; these proportions used throughout on manufacturer's recommendation). First coat applied afternoon of November 18; partially washed off by heavy rain night of November 18, remainder scraped off, and base wire brushed, hosed, and replastered morning of November 19; second coat

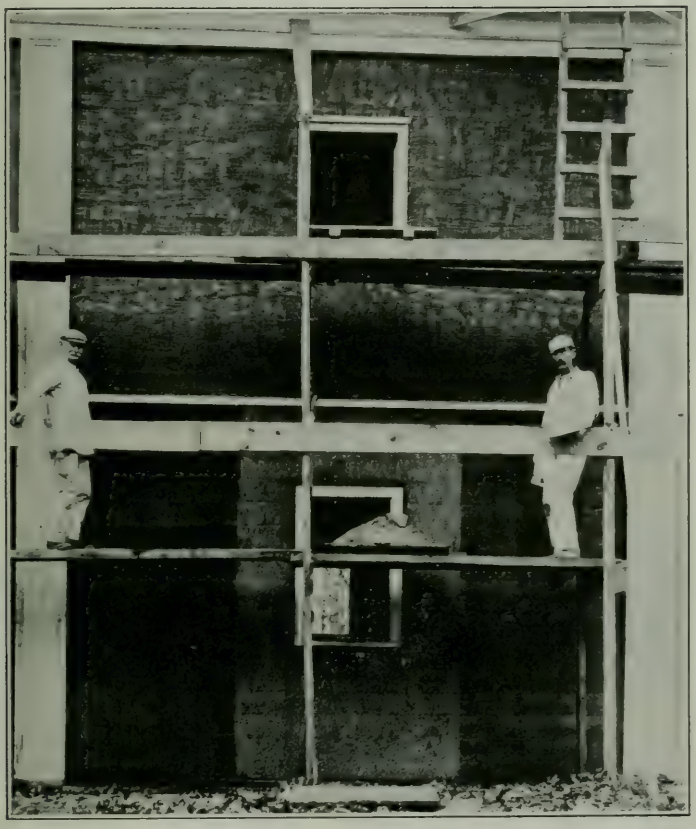

FIG. 30.—*Treated concrete base of panel No. 47 (lower) ready for plastering. Left section scrubbed with muriatic acid, middle section roughened with stone pick, right section scrubbed with acetic acid. Scratch coat on panel No. 8 shown above*

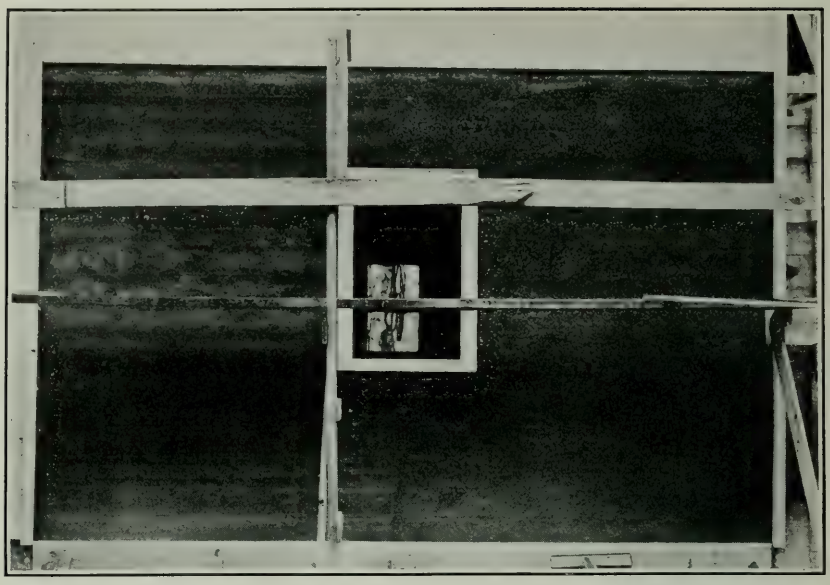

FIG. 31.—*Concrete base of panel No. 49, left half untreated, right half wire brushed. (The smoother portions of the right half were rebrushed after the photograph was taken and just before plastering was begun)*

FIG. 32.—*"Bishopric Board" on panal No. 51, left half creosoted lath, right half uncreosoted lath. Same construction on panel No. 52*

applied morning of November 22, finish coat laid on morning of November 24, finished 2 p. m. (Fig. 9 shows this panel after application of scratch coat.)

Weather: Freezing temperatures recorded November 22, 23, 25, 28, and 30; showers afternoon of November 19, panel protected with tarpaulin; gusty wind November 21; cold northwest wind November 22; rain at night November 23; cold northwest wind November 29.

Superficial inspection: Color, light, uniform; no cracks; float marks somewhat visible; appearance very good.

Detailed inspection: Fine body cracks only, mostly vertical and horizontal and short, a few extend across panel; bond good; condition good.

Panel No. 50

Location: East side, first story, fifth panel from south end.

Construction: Monolithic concrete, poured November 18; forms removed and base treatment given prior to plastering November 19; upper half not roughened; lower half wire brushed; left half coated with 1:1 grout, right half coated with 1:2 grout.

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied afternoon of November 19; second coat morning of November 22; finish coat laid on 11 a. m., November 24; finished 1.30 p. m.

Weather: Freezing temperatures recorded November 22, 23, 25, 28, and 30. showers afternoon of November 19, panel protected with tarpaulin; gusty wind November 21; cold northwest wind November 22; rain at night of November 23; cold northwest wind November 29.

Superficial inspection: Color, dark gray, not wholly uniform; no cracks; rough finish general appearance excellent.

Detailed inspection: A number of surface cracks faintly visible: bond good; condition excellent.

GROUP XI

Miscellaneous. This group includes three panels of which the bases are special proprietary materials

Panel No. 51

Location: East side, first story, third panel from south end (door panel).

Construction: Bishopric board, left half creosoted lath (sec. a), right half plain lath (sec. b). (Shown in Fig. 32.)

Stucco: A–1 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 3 sand). First coat applied afternoon of October 19; second coat morning of October 20; finish coat laid on morning of October 25; finished afternoon. Lath thoroughly wetted before plastering.

Weather: Heavy rain early morning of October 20; gusty southeast wind afternoon developed into thunder shower 8 p. m., October 26; moderately gusty wind October 30; no freezing.

Superficial inspection: Color, uniform light gray; many prominent cracks; float marks not noticeable; general appearance fair (good except for cracks).

Detailed inspection: Structural, fundamental, and body cracks; most cracks do not follow joints in board, but many are parallel to lath; right half appears to have bulged outward slightly; bond good; condition poor.

Remarks: Bishopric board is a proprietary stucco or plaster board, consisting of wood lath backed with paper which is first given a heavy coat of asphaltic compound on the lath side. This compound serves as a waterproof coat and as an adhesive between the lath and paper. The lath are dovetailed in order to insure a firm key for the plaster. The board is shipped in rolls containing 100 square feet and is applied in such manner as to break joints every 3 or 4 feet. (See Fig. 32.) Bishopric board may be applied over sheathing or directly to studs.

Panel No. 52

Location: East side, first story, third panel from north end (door panel).

Construction: Bishopric board, left half creosoted lath (sec. a), right half plain lath (sec. b), same as panel 51. (See Fig. 32.)

Stucco: B–1 (parts by weight, 0.25 cement, 0.75 high calcium hydrated lime, 3 sand; second and third coats 4 parts sand). First coat applied November 9; second coat afternoon of November 11; finish coat laid on morning of November 17; finished afternoon. Lath thoroughly wetted before plastering.

Weather: Freezing temperatures recorded November 16, 17, 18, 22, and 23; moderate rain in afternoon of November 12; moderate rain throughout day November 14; rain early morning, gusty northwest wind afternoon of November 15; cold northwest wind November 16; heavy southeast storm night of November 18; showers afternoon of November 19; gusty wind November 21; cold northwest wind November 22; rain at night of November 23.

Superficial inspection: Color, light, uniform, but shows efflorescence; several prominent cracks; surface smooth; general appearance fair (good except for cracks).

Detailed inspection: Two structural cracks, some surface and fundamental cracks, many body cracks; cracking does not usually occur at joints in board; bottom flaking somewhat, especially under doorsill, apparently due to moisture and frost action; bond good; condition very poor.

Panels Nos. 53, 54, and 55

See Groups VII, II, and I, respectively.

Panel No. 56

Location: West side, second story, south-end panel.

Construction: "Clinton welded sheathing" applied directly to studs 16 inches apart, the latter being braced on the inside in the same manner as the back-plastered panels of Group III.

Stucco: A–4 (parts by weight, 1 cement, 0.1 high magnesian hydrated lime, 4 sand). First coat applied with difficulty, on account of cold, wet weather, lean mixture, and wide spacing of wires, morning of February 2, 1916. Surface freezing two hours after application. Second coat applied morning of February 7, first coat being first well broomed and rescratched with nail; first coat not very hard at this time. Rapid fall in temperature afternoon of February 7, with fresh northwest wind; surface freezing at 4.30 p. m. Third coat applied morning of February 18, finished 4 p. m.; weather fair and moderate temperature; in late afternoon conditions of February 7 repeated, and finish coat was slightly surface frozen during the night.

Weather: Freezing temperatures recorded on all days from February 2 to February 24, inclusive, except the 12th, 18th, and 23d. Severest weather of winter occurred in this interval. During the entire month the panel was protected by tarpaulin tacked to cornice and hung over scaffolding.

Superficial inspection: Color, dark gray, nonuniform; surface scaling slightly in spots; no cracks; rough finish; general appearance poor.

Detailed inspection: No cracks; bond good; condition excellent.

Remarks: "Clinton welded sheathing" is a proprietary stucco or plaster board consisting of a series of parallel No. 13 galvanized wires, spaced 3 inches apart and running horizontally, welded to a series of similar wires spaced 8 inches apart and running vertically, with tarred felt or sheathing paper laid between the two sets of wires before welding. The paper is punched at points where the wires intersect, which permits of welding and affords a small key for the plaster at each intersection. The material is applied directly to studs 16 inches apart, with the horizontal wires outside. The plaster is applied directly against the felt and imbeds the horizontal wires completely between the points of support.

In the foregoing notes it will be observed that the finish coats of the cement stuccos were frequently too wet to finish to best advantage, evidence of which is not lacking in the appearance of the panels at the present time. It is believed that while this was partly due to the cool weather which prevailed during the latter part of the work and the consequent slower setting of the mortar, the majority of such cases were due to excessive wetting of the under coats combined with a tendency of the plasterers to use too wet a mix to permit of finishing within the desired time. The change in the method of finishing the cement panels instituted on November 5, required better control of the consistency and, gennerally speaking, the use of a stiffer mix than the plasterers were accustomed to use. Probably no less important, however, is the control of the absorption or "suction" of the under coats by the proper amount of sprinkling or spraying just before the finish coat is applied.

In order to facilitate comparisons between panels of similar construction, the panel numbers are grouped in the following table, both according to bases and stuccos.

TABLE 1

Grouping the Test Panels According to Stuccos and Bases

Stuccos (parts by weight)	Bases											
	Metal lath			Wood lath		Gypsum plaster board (Group VI)	Terra-cotta tile (Group VII)	Brick (Group VIII)	Gypsum block (Group IX)	Monolithic concrete (Group X)	Proprietary bases (Group XI)	Total number of panels
	Group I	Group II	Group III	Group IV	Group V							
A–1 (1 cement, 0.1 magnesian hydrated lime, 3 sand)	1	10	15			26	[a] 30	39	42	45	[b] 51	
	2	12				27	31	[c] 41	43	46		
		[d] 54				28	35		44	47		26
						29	38			[d] 48		
							[d] 53			50		
A–2 (0.75 cement, 0.25 magnesian hydrated lime, 3 sand)	3						36					2
A–3 (1 cement, 0.1 calcium hydrated lime, 3 sand)				18	21							
					24							3
A–4 (1 cement, 0.1 magnesian hydrated lime, 4 sand)											[e] 56	1
B–1 (0.25 cement, 0.75 calcium hydrated lime, 3 sand; second and third coats, 4 sand)			16		22		32				[b] 52	5
					25							

[a] Hollow concrete block.
[b] "Bishopric board."
[c] Unfinished.
[d] Coated with cement gun.
[e] "Clinton welded sheathing."

TABLE 1—Continued

Stuccos (parts by weight)	Bases											
	Metal lath			Wood lath		Gypsum plaster board (Group VI)	Terra-cotta tile (Group VII)	Brick (Group VIII)	Gypsum block (Group IX)	Monolithic concrete (Group X)	Proprietary bases (Group XI)	Total number of panels
	Group I	Group II	Group III	Group IV	Group V							
B–2 (0.25 cement, 0.75 magnesian hydrated lime, 3 sand; second and third coats, 4 sand)	3	11	.....	19	.....	.....	.....	40	.....	.....	.....	5
			.....	20	.....	.....	.....	.....	.....	.....	.....	.....
C–1 (1 "Alca" lime, 3.5 sand; second and third coats, 4 sand)	4	13	.....	.....	23	.....	33	.....	.....	49	.....	5
C–2 (0.75 "Alca" lime, 0.25 cement, 3.5 sand; second and third coats, 4 sand)	55	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
D–1 (1 cement, 2.5 sand)	.....	.....	.....	.....	.....	.....	34	.....	.....	.....	.....	1
D–2 (1 cement, 2 sand; second and third coats, 3 sand)	5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
D–3 (1 cement, 3 sand)	6	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
E (0.5 cement, 0.5 magnesian hydrated lime, 3 sand; second and third coats, 4 sand	.....	.....	17	.....	.....	.....	.....	.....	.....	.....	.....	1
F–1 (1 cement, 0.02 "Medusa" W. P. compound, 3 sand)	7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
F–2 (1 cement, 0.09 "Impervite" W. P. compound, 3 sand)	8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
G–1 (1 cement, 0.3 magnesian hydrated lime, 3 sand; second coat, 1 white cement, 0.1 magnesian hydrated lime, 2 white silica sand)	.....	.....	.....	.....	.....	.....	37	.....	.....	.....	.....	1
G–2 (1 cement, 0.1 magnesian hydrated lime, 3 sand; third coat, 1 white cement, 0.1 magnesian hydrated lime, 3 limestone screenings)	.....	.....	14	.....	.....	.....	.....	.....	.....	.....	.....	1
Total number of panels	10	5	4	3	5	4	10	3	3	6	3	56

VI. WEATHER CONDITIONS DURING PLASTERING OF PANELS

The following notes on the daily weather conditions during the plastering of the test structure are taken mainly from the Monthly Meteorological Summary published by the Weather Bureau, Department of Agriculture, Washington, D. C., and supplemented by general observations at the work from day to day. For convenience these notes are presented in tabular form, which is in effect a rearrangement of the Weather Bureau's tables.

The plastering was begun October 19 and completed November 25; the data are given for the period October 19 to November 30, inclusive.

TABLE 2

Summary of Weather Conditions During the Plastering of the Test Panels

Date	Temperature			Precipitation	Character of day	Per cent possible sunshine	Remarks
	Max.	Min.	Mean				
	Deg.	Deg.	Deg.	Inches			
Oct. 19	75	60	68	0.01	Cloudy	44	Warm and damp.
Oct. 20	72	63	68	.47	do	4	Heavy rain early morning, later warm and damp.
Oct. 21	79	60	70		Clear	75	Sprinkling of plaster coats begun to-day and continued thereafter twice daily until November 3.
Oct. 22	69	50	60		do	97	Very little breeze to date.
Oct. 23	60	37	48		do	100	Moderate breeze.
Oct. 24	55	35	45		do	100	Northerly breeze. Panels wet down once only.
Oct. 25	62	34	48		do	100	Heavy frost; no indication of plaster freezing.
Oct. 26	75	51	63	.07	do	92	Increasing cloudiness and gusty southeast wind in afternoon developed into thunder shower about 8 p. m.
Oct. 27	70	48	59		do	88	
Oct. 28	64	41	52		do	100	Near frost this morning.
Oct. 29	74	47	60	Trace	Part cloudy	83	Very little breeze.
Oct. 30	63	49	56		Clear	100	Cool and moderate breeze in morning, somewhat gusty in afternoon.
Oct. 31	58	40	54		do	100	Light breezes, panels wet down once only.
Nov. 1	77	49	63		Part cloudy	93	Light breezes.
Nov. 2	70	48	59		Clear	93	High winds.
Nov. 3	53	39	46		do	96	Cold wind, less violent than yesterday. Last day for regular sprinkling of finished coats.
Nov. 4	51	34	42	.02	Cloudy	19	Rain at intervals, moderate wind.
Nov. 5	59	41	50		Part cloudy	79	Breezy, warmer than past two days.
Nov. 6	49	34	42		Clear	100	Very little wind; heavy frost this morning, but no indication of freezing.
Nov. 7	57	35	46		do	100	
Nov. 8	60	33	46		Part cloudy	74	Gentle breeze.
Nov. 9	69	45	57		Clear	100	Moderate breezes.
Nov. 10	57	37	47		do	98	Do.
Nov. 11	64	37	50		Part cloudy	67	Very little breeze.
Nov. 12	71	50	60	.03	Cloudy	21	Rain in afternoon.
Nov. 13	58	41	50		Part cloudy	94	Little wind, ideal for exterior plastering.
Nov. 14	46	36	41	.21	Cloudy	0	Rain throughout day.
Nov. 15	52	37	44	.06	Part cloudy	61	Rain in early morning, ceased about 8.30 a. m. Gusty northwest wind last of afternoon, with decided drop in temperature.

TABLE 2—Continued.

Date	Temperature			Precipitation	Character of day	Per cent possible sunshine	Remarks
	Max.	Min.	Mean				
	Deg.	Deg.	Deg.	Inches			
Nov. 16	44	31	38	.....	Part cloudy	93	Light freeze this morning, with cold northwest wind. (See notes under description of panels 7, 16, 36, and 40.)
Nov. 17	52	27	40	.....	Clear	100	Light freeze this morning. Very little breeze. No indications of plaster freezing.
Nov. 18	50	27	38	.02	Part cloudy	79	Little or no ice observed this morning and no indications of plaster freezing. Fair and moderate temperature during morning, cloudy and chilly afternoon.
Nov. 19	64	46	55	.53	do	60	Heavy southeast storm and rain last night. (See notes under description of panels 8, 34, 45, 47, and 49.) Heavy clouds and showers in afternoon.
Nov. 20	57	41	49	.....	do	85	Breezy.
Nov. 21	62	41	52	.....	Cloudy	32	Mild, gusty winds.
Nov. 22	41	31	36	.....	Clear	94	Light freeze this morning, with cold northwest wind. No indication of plaster freezing.
Nov. 23	43	25	34	.05	Cloudy	0	Ice $\frac{1}{16}$ inch thick observed near test structure, but no indication of freezing of coats applied yesterday. (See notes under description of panel 7.) Chilly south breeze.
Nov. 24	49	34	42	.....	Part cloudy	79	
Nov. 25	52	32	42	.....	do	67	
Nov. 26	59	34	46	.....	do	77	See notes under description of panels 7 and 8.
Nov. 27	63	41	52	.01	do	61	
Nov. 28	55	31	43	.....	do	78	
Nov. 29	50	34	42	Trace.	Cloudy	22	Cold northwest winds.
Nov. 30	39	27	33	.....	Clear	94	Light freeze early morning, cool and breezy during day.

The foregoing summary indicates that the plastering of the test panels was done under generally favorable conditions; better, in fact, than might have been expected for the time of year. On two or three occasions only was there any question of the possibility of freezing. Aside from these and the rather cold days at the end when the concrete panels were being finished, better weather could not reasonably have been desired.

In order that one may obtain a general idea of the exposure of the panels up to the April inspection, and also compare the temperature extremes and variations with those in other parts of the

country, a complete daily temperature record from October 19, 1915, to April 7, 1916, is given in Fig. 33. The curves represent

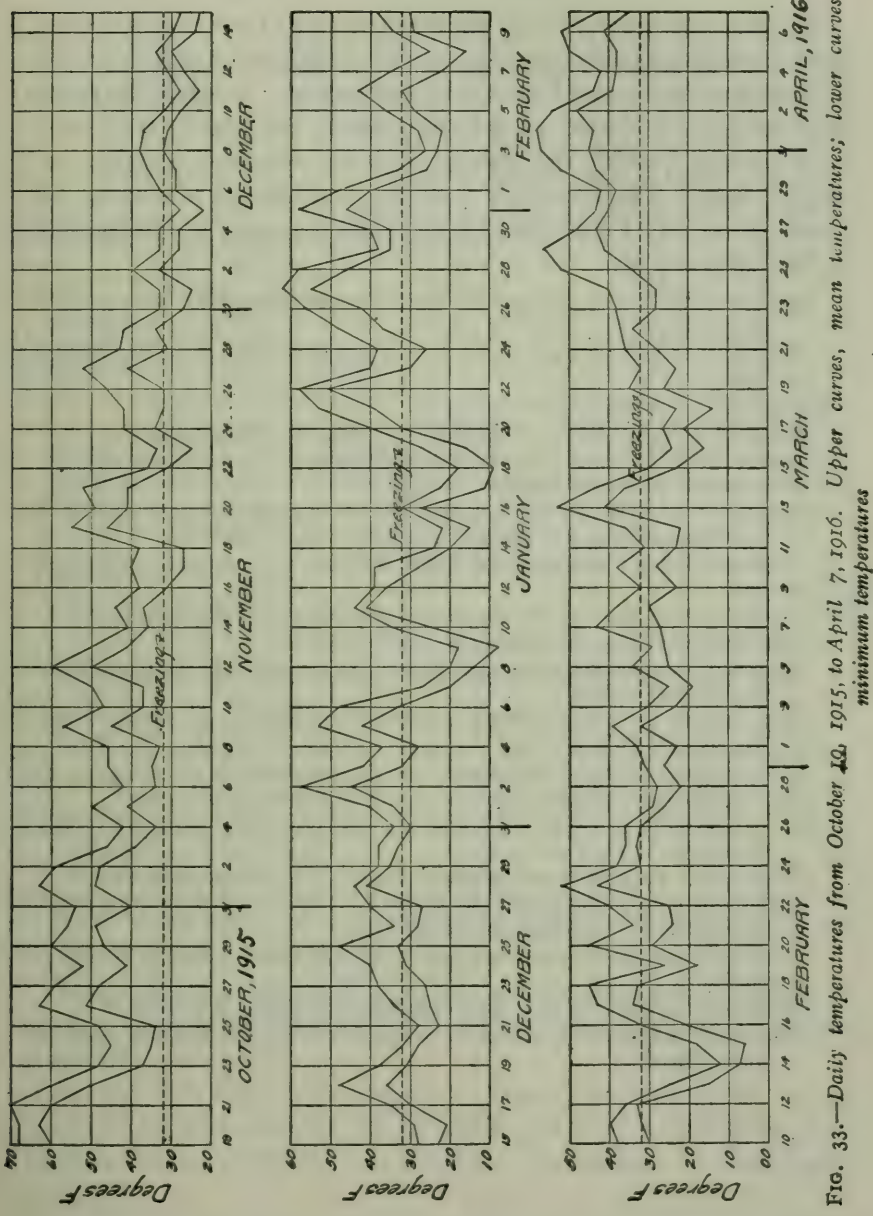

FIG. 33.—*Daily temperatures from October 19, 1915, to April 7, 1916. Upper curves, mean temperatures; lower curves, minimum temperatures*

the mean and minimum temperatures, and the maximum can be obtained, if desired, by adding the difference between mean and minimum to the former.

VII. SOURCES AND SUPPLEMENTARY TESTS OF MATERIALS USED IN CONSTRUCTION OF THE TEST PANELS

All materials entering into the construction of the test structure, aside from the panels themselves, were purchased from the funds appropriated or donated for the investigation. This applies to the steel and concrete work of the foundation, the lumber and hardware used in framing the structure, doors, windows, roofing, and outside trim. The materials used in erecting and plastering the panels were partly purchased and partly donated as enumerated in the following list:

Metal lath and furring, donated by the Associated Metal Lath Manufacturers, Chicago, Ill.

Wire lath and wire netting, donated by the Clinton Wire Cloth Co., Clinton, Mass.

Wood lath, purchased in local market.

Hollow tile, donated by the National Fireproofing Co., Pittsburgh, Pa.

Concrete block, purchased from local manufacturer.

Brick, purchased in local market.

Gypsum block and plaster board, donated by the Gypsum Industries Association, New York, N. Y.

"Bishopric board," donated by the Mastic Wall Board & Roofing Co., Cincinnati, Ohio.

"Hydronon," donated by the Barrett Manufacturing Co., New York, N. Y.

"Antihydrine," taken from a sample submitted for test.

"Medusa" waterproofing compound, donated by the Sandusky Portland Cement Co., Sandusky, Ohio.

White "Impervite" waterproofing compound, donated by the Standard Paint Co., New York, N. Y.

Cement, purchased in the local market under Government specification.

Sand, gravel, and limestone screenings, purchased in the local market.

White silica sand and White Portland cement, donated by the Atlas Portland Cement Co., New York, N. Y.

"Alca" lime, donated by the Aluminate Patents Co., Philadelphia, Pa.

Hydrated lime, donated by the Hydrated Lime Bureau of the National Lime Manufacturers Association, Pittsburgh, Pa.

"Parlock" materials, donated and applied by the Mastic Bond Co., New York, N. Y.

Cement gun panels, coated by the Cement Gun Co. (Inc.), New York, N. Y.

"Ruberoid" sheet roofing, purchased at cost price from the Standard Paint Co., New York, N. Y.

The majority of these materials have been submitted to the usual laboratory tests, the results of which are as follows:

TABLE 3

Chemical Analyses of Expanded Metal and Wire Lath

Chemical analysis	No. 8214 Galvanized-wire lath, 20-gauge	No. 8215 Painted diamond-mesh expanded lath, 24-gauge	No. 8216 Painted ribbed expanded lath, 26-gauge	No. 8217 Diamond-mesh expanded lath [a]	No. 8218 Diamond-mesh expanded lath [b]
Carbon	0.034	0.046	0.086	0.042	0.064
Sulphur	.072	.065	.048	.026	.034
Phosphorous	.099	.088	.056	.063	.091
Manganese	.33	.44	.26	.32	.35
Copper	.006	.007	.018	.006	.010
Zinc [c]	31.6	.....	.....	30.8	13.4

[a] Galvanized after expansion, 27-gauge.

[b] Cut from galvanized sheets, 27-gauge.

[c] Zinc is expressed as per cent of weight of original sample, each value being the average of three determinations.

CHEMICAL ANALYSES OF BONDING MATERIALS

Hydronon, Lab. No. 8251:	Per cent.
Volatile in 24 hours at 105° C	72.8
Nonvolatile [1]	27.2

Paint dries hard in 1 hour, and after heating to 105° C for 24 hours film is hard and somewhat brittle.

Tests indicate material is a coal tar thinned with a coal-tar naphtha.

Lifekote Dampproofing Bond, "Parlock" coating, Lab. No. 7645:	Per cent.
Volatile in 24 hours at 105° C	29.3
Nonvolatile [2]	70.7

Paint dries tacky in 1½ hours and after heating to 105° C for 24 hours is hard and slightly brittle.

Tests indicate material is a mixture of asphalts in which is some Trinidad asphalt fluxed with fatty material and thinned with a petroleum thinner.

NOTE.—The sample analyzed was taken from a small remaining quantity of material which had stood about 18 hours in an open bucket. This accounts for the high percentage of nonvolatile matter.

[1] Character of nonvolatile, hard and brittle. [2] Character of nonvolatile, hard and elastic.

Antihydrine, Lab. No. 1829:	Per cent.
Volatile in 24 hours at 105° C	38.8
Nonvolatile [4]	61.2
Ash [5]	3.24
Fixed carbon	9.88
Distillation—	
100°–250° C	39.4
Specific gravity	.743
Color	Clear.
250°–350° C	11.8
Specific gravity	.841
Color	Light brown.
Residue [6]	48.8

Paint dries faintly tacky in 4 hours, and after heating to 105° C for 24 hours film is soft and elastic.

Tests indicate material is a series of fluxed asphalts thinned with a petroleum product. There are also present some fatty acids.

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[4] Character of nonvolatile, moderately hard and plastic.
[5] Ash is chiefly silica and oxides of iron and aluminum.
[6] Character of residue, soft and plastic when cold, fluid when hot.

TABLE 4

Chemical and Physical Tests of Cements, Limes, and Integral Waterproofings

Chemical analyses and physical tests	"Tidewater" Portland cement		"Atlas" white Portland cement		"Limoid" high mag. hyd. lime		"Berkeley" high cal. hyd. lime		"Alca" lime (high mag. hyd. lime+Ca. aluminate)				"Medusa" waterproofing compound [a]	White "Impervite" waterproofing [b]
	No. 7300	No. 7993	No. 7989	No. 7994	No. 7301	No. 7995	No. 7880	No. 7998	No. 7489	No. 7490	No. 7882	No. 7997	No. 7996	No. 8235
Silica (SiO_2)	21.70	.....	.....	.....	3.30	2.46	1.60	1.80	4.64	4.80	4.92	5.14	Analysis indicates that this material is composed of approximately 1 part lime soap and 3 parts hydrated lime.	Analysis indicates that this material is composed of approximately 3 parts hydrated lime, 3 parts vaseline, and 4 parts water.
Iron oxide (Fe_2O_3)	3.15	.....	0.40	0.40	.10	trace	trace	trace	trace	.10	trace	trace		
Alumina (Al_2O_3)	6.55	.....	.....	.....	1.04	1.04	1.00	.96	5.90	3.56	4.16	4.02		
Calcium oxide (CaO)	59.80	.....	.....	.....	47.40	47.30	68.90	70.00	46.20	45.70	45.50	45.40		
Magnesium oxide (MgO)	2.72	2.64	1.64	1.68	31.80	30.84	2.40	1.84	27.12	29.20	29.20	28.00		
Sulphuric anhydride (SO_3)	1.62	1.44	1.75	1.69	.64	.46	.59	.56	1.14	.80	.88	.83		
Ignition loss	2.18	1.29	2.88	2.67	16.82	17.63	23.85	23.96	15.37	15.10	14.46	15.12		
Carbon dioxide (CO_2)	.....	.....	.....	.....	.93	1.47	2.40	2.57	.80	.76	.90	1.27		
Insoluble residue	.33	.36	.50	.26	.89	1.35	trace	trace	.25	.99	1.12	1.26		
Specific gravity	3.20	3.20	3.11	3.07	2.60	2.71	2.33	2.40	2.61	2.61	2.61	2.59		
Fineness No. 100	96.0	95.6	99.8	99.6	98.2	94.8	99.8	99.9	94.0	93.6	96.0	97.6	.....	.....
Fineness No. 200	79.1	77.0	89.4	90.5	89.9	92.4	96.6	98.3	88.3	80.1	72.4	88.9	.....	.....
Soundness	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	O. K.	.....	.....
Initial set	5:12	2:07	2:57	3:09	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Final set	8:33	7:12	5:57	8:24	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Tensile strength: 1:3—														
7-day average	233	197	237	230	.....	.....	.....	.....	51	70	34	52	.....	.....
28-day average	402	305	358	397	.....	.....	.....	.....	110	114	108	98	.....	.....
Lime plus magnesia, per cent of nonvolatile matter	.....	.....	.....	.....	94.69	95.71	96.48	96.30	.....	.....	.....	.....	.....	.....

PHYSICAL TESTS OF SANDS

Samples of sand were taken from nearly all deliveries for screen analysis and for moisture and silt determinations. The samples were taken at such time as to include the probable extremes of moisture conditions as well as the average conditions under which the sand was used.

The results of moisture and silt determinations, as obtained from the river sands, are as follows:

Laboratory No.	Per cent moisture	Per cent silt	Laboratory No.	Per cent moisture	Per cent silt
7302	7.9	2.68	7986	11.1	2.14
7488	3.6	2.12	7990	7.7	2.00
7639	6.2	2.70	7991	7.1	2.81
7640	9.1	2.46			
7642	5.2	2.76	Mean	7.36	2.49
7643	8.3	2.76			

The foregoing values were obtained by drying 200 g. samples to constant weight and computing the silt and moisture percentages on the basis of the dry weight.

The screen analyses were made on the Tyler screen scale series of 13 sieves from the 3-mesh to the 150-mesh, inclusive. The results are given in Table 5, showing the percentages of the various sands passing the sieves.

TABLE 5

Mechanical Analyses of Sands[a]

Sieve No.	Potomac River sand										"Parlock" sand	Limestone screenings	Silica sand
	No. 7302	No. 7486	No. 7639	No. 7640	No. 7642	No. 7643	No. 7986	No. 7990	No. 7991	Average	No. 7641	No. 7855	No. 7988
3	99.4	100.0	.....	100.0	100.0	99.4	100.0	100.0	99.6	99.8	.....	.....	.....
4	99.1	99.9	100.0	97.4	99.9	99.3	99.8	99.5	99.5	99.3	.....	100.0	.....
6	98.7	99.8	99.5	97.3	99.7	99.1	99.7	99.3	99.3	99.1	100.0	99.6	100.0
8	98.4	99.6	99.3	96.8	99.3	98.8	99.4	98.8	99.0	98.8	99.9	99.4	99.8
10	97.9	99.1	98.8	94.8	98.6	98.3	97.9	97.3	98.4	97.7	98.2	91.1	99.6
14	97.1	98.2	98.0	90.1	97.4	97.4	94.7	94.1	97.4	95.6	80.4	79.4	96.7
20	95.2	96.0	96.2	80.9	94.8	95.3	88.0	87.3	94.7	91.0	45.9	67.9	69.3
28	89.3	89.2	91.0	65.7	87.5	88.8	73.5	71.8	87.8	80.9	10.3	56.5	34.9
35	77.8	75.8	81.3	50.5	74.5	76.6	54.2	54.5	75.4	66.7	.9	48.5	27.7
48	49.2	44.2	54.9	27.9	45.5	47.4	29.9	28.6	46.1	40.0	.4	39.4	21.5
65	25.7	20.3	27.5	14.9	21.8	22.9	14.1	13.6	22.8	19.7	.2	32.5	16.9
100	9.2	6.6	8.8	6.5	6.7	8.6	4.0	3.8	8.1	6.6	.1	24.7	11.8
150	3.8	2.8	3.1	3.0	2.6	3.9	1.6	1.5	3.6	2.8	.1	18.2	7.5

[a] In column 11, headed "Average," are given the average percentage of the nine river sands passing each sieve. In Fig. 34 this average sand is plotted, together with the highest and lowest values of all the river sands. It will be noted that with the exception of two or three values on the finest screens, the highest values are given by sample No. 7639 and the lowest by sample No. 7640; that is, No. 7639 is the finest sand used (of the river sands) and No. 7640 is the coarsest, all the others lying between these two and not differing greatly from the "average" sample. The diagram also gives the curves of the special sands.

WEIGHT-VOLUME RELATIONS OF STUCCO MATERIALS

Because of the indefiniteness of volume measurements of cement, sand, lime, etc., the stucco materials used in the investigation have been proportioned in all cases by weight. It is customary in commercial practice, however, to specify the proportions of plaster mixtures by volume on account of the fact that it is more or less impracticable to weigh all materials as they are used "on the job." For purposes of comparison weight-volume determinations were made on the majority of materials used in the tests, the materials being shoveled, scooped, or poured into a 1 cubic-

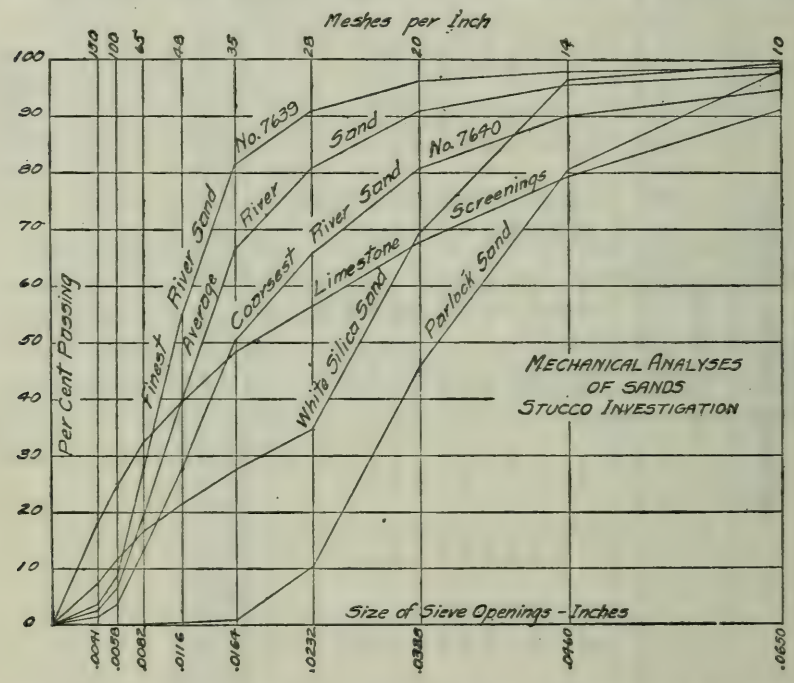

FIG. 34.—*Curves showing the granulometric composition of sands used in the stuccos*

foot measure, without special compacting, in a manner which imitates as nearly as possible that used in commercial practice.

The following results were obtained from a number of trials on each material:

	Weight of 1 cubic foot in pounds.
River sand (damp, shoveled in)	83
"Alca" lime (scooped from sack)	41
"Limoid" (high, magnesian hydrated lime, scooped from sack)	36
"Berkeley" (high calcium hydrated lime, poured from sack)	36
"Tidewater" (cement, poured from sack)	94
White silica sand (poured dry)	93
Limestone screenings (poured dry)	106

On the basis of the foregoing figures the stuccos are given in the following table, both by weight and volume proportions:

TABLE 6

Weight-Volume Relations of Stucco Materials

Stucco	Proportions by weight	Proportions by volume
A-1, A-3	1 cement, 0.1 hydrated lime, 3 sand	1 cement, 0.26 hydrated lime, 3.4 sand.
A-2	0.75 cement, 0.25 hydrated lime, 3 sand	0.75 cement, 0.65 hydrated lime, 3.4 sand.
A-4	1 cement, 0.1 hydrated lime, 4 sand	1 cement, 0.26 hydrated lime, 4.5 sand.
B-1, B-2	0.25 cement, 0.75 hydrated lime, 3 sand (second and third coats 4 sand).	0.25 cement, 1.96 hydrated lime, 3.4 sand (second and third coats 4.5 sand).
C-1	1 Alca lime, 3.5 sand (second and third coats 4 sand).	1 Alca lime, 1.7 sand (second and third coats 2.0 sand).
C-2	0.75 Alca lime, 0.25 cement, 3.5 sand (second and third coats 4 sand)	0.75 Alca lime, 0.12 cement, 1.7 sand (second and third coats 2.0 sand).
D-1	1 cement, 2.5 sand	1 cement, 2.8 sand.
D-2	1 cement, 2 sand (second and third coats 3 sand).	1 cement, 2.3 sand (second and third coats 3.4 sand).
D-3	1 cement, 3 sand	1 cement, 3.4 sand.
E	0.5 cement, 0.5 hydrated lime, 3 sand (second and third coats 4 sand).	0.5 cement, 1.3 hydrated lime, 3.4 sand (second and third coats 4.5 sand).
F-1	1 cement, 0.02 Medusa waterproofing compound, 3 sand.	1 cement, 3.4 sand (volume of Medusa waterproofing compound not determined).
F-2	1 cement, 0.09 Impervite waterproofing compound, 3 sand.	1 cement, 0.13 Impervite waterproofing compound, 3.4 sand.
G-1	1 cement, 0.3 hydrated lime, 3 sand (second coat, 1 white cement, 0.1 hydrated lime, 2 white silica sand).	1 cement, 0.78 hydrated lime, 3.4 sand (second coat, 1 white cement, 0.26 hydrated lime, 2.0 white silica sand).
G-2	1 cement, 0.1 hydrated lime, 3 sand (third coat, 1 white cement, 0.1 hydrated lime, 3 limestone screenings).	1 cement, 0.26 hydrated lime, 3.4 sand (third coat, 1 white cement, 0.26 hydrated lime, 2.7 limestone screenings).

In the foregoing table it should be noted that the river sand was measured and weighed damp, as used. If the sand had been measured dry, its weight per cubic foot would undoubtedly have been higher and the volume proportions of sand would have been somewhat less. For practical purposes, however, it is sufficient to remember that the volume proportions of cement and sand are approximately equal to their weight proportions, but since the weight of hydrated lime per cubic foot is less than half the weight of cement, a mixture of 1 part hydrated lime to 2 parts of sand by volume is nearly equivalent to a 1:4 proportion by weight.

VIII. SUMMARIZED REPORT ON CONDITION OF TEST PANELS

This report on the condition of the test panels embodies the results of two independent inspections, the first made on April 4 and 5 by Messrs. Bagnall, Earley, and Humphreys, expert plasterers and members of the advisory committee, and the second made on April 6 and 7 by Messrs. Wig, Pearson, and Emley of this Bureau. The same general plan was followed in the two inspections, viz, first a superficial examination was made in which the general condition and appearance of the panels was noted; then, a close and careful inspection was made immediately after spraying the panels with water. This treatment brings out very fine surface cracks and other defects which are not otherwise easily observed in the dry panels.

In the superficial examination the panels were observed from a distance of about 30 feet and notes made upon the color, uniformity of color, visible cracks, float marks, and general appearance. Under the general appearance, panels are rated as excellent, very good, good, fair, poor, and very poor, all conditions effecting appearance being taken into consideration except color. The notes tabulated below are self-explanatory, except under "float marks," which are designated as rough, medium, slightly visible, and smooth. These terms are intended to describe the relative combined effects of texture and evenness of floating and indicate in a general way the character of the surface finish.

In the detailed examination attention has been given mainly to defects due to construction, viz, cracks, separation of plaster coats, etc. An attempt has been made to divide cracks into four classes as follows: (1) Surface cracks, which are usually very fine and do not appear to penetrate into the body of the stucco. These cracks include, but are not limited to, the type commonly called "crazing," and are presumably caused by the effects of temperature changes and of alternate wetting and drying on the thin film of weak cementing material brought to the surface on finishing. (2) Body cracks, which appear to have some depth and may penetrate into the body of one or more coats of the stucco. These cracks, usually fine, are characterized by sharp, clean-cut edges, and are assumed to result from excessive strains in the body of the stucco set up by temperature changes, alternate wetting and drying, or by any causes which may induce differential movements between the plaster coats. It is frequently impossible to distinguish such

cracks from (3) Fundamental cracks, which appear to penetrate all coats of the stucco, but are not structural cracks. Thus fundamental cracks may appear over wood lath, over joints in wood lath, plaster board, or metal lath, over studs where sheathing is not used, or over joints in tile, concrete block, etc. The origin of such cracks is attributed to excessive strains set up by movements in the base which supports the stucco. (4) Structural cracks, which appear to be caused by settlement or movement of some part of the building and are not to be attributed to faults in the stucco itself or in its supporting base. Under "condition" in the following table the panels are rated on integrity alone, except that structural cracks are not taken into consideration. This exception is made on the ground that faults in construction of the building should not be charged against any particular stucco and its supporting base, although in residence construction such faults may not always be easily guarded against. It should be stated also that in assigning the rating surface cracks have been considered less serious than body cracks, and body cracks less serious than fundamental cracks.

The results of the inspection are given in tabular form on pages 60–66, and so arranged that they may be examined with easy reference to the panel plan, Fig. 35.

TABLE 7

Showing Condition of the Test Panels April 7, 1916

Panel No.	Base	Stucco	Superficial inspection				
			Color	Uniformity of color	Cracks	Float marks	Appearance
1	Metal lath	A-1	Light gray	Not wholly uniform	Prominent structural only	Rough	Fair to good.
2	do	A-1	do	do	do	do	Do.
3	do	B-2	Buff	Nonuniform dark patches	Structural and other prominent cracks.	Medium	Poor.
4	do	C-1	Buff to light buff	Not wholly uniform	Numerous, more or less visible.	do	Fair to poor.
5	do	D-2	Medium gray	Uniformly mottled	Structural cracks visible	Brush marks visible	Good.
6	do	D-3	do	Nonuniform	Structural only	Medium	Fair.
7	do	F-1	do	do	None	Rough	Do.
8	do	F-2	Dark gray	Uniform	Structural faintly visible	do	Very good.
9	do	A-2	Light buff	Badly streaked. Furring appears to show through.	Few structural only	Brush marks slightly visible.	Fair (good if not streaked).
10	do	A-1	Light gray	Not wholly uniform	Structural and other prominent cracks.	Rough	Fair.
11	do	B-2	Buff	Uniform, slight efflorescence.	Structural only	Medium	Very good.
12	do	A-1	Light gray	Uniform	do	Rough	Good.
13	do	C-1	Light (nearly white)	Not wholly uniform	Covered with prominent cracks.	Smooth	Very poor.
14	do	G-2	White	Uniform	None	Slightly visible	Excellent.
15	do	A-1	Dark gray	do	do	Rough	Do.
16	do	B-1	Light buff	Not wholly uniform	Structural only faintly visible.	Slightly visible	Good.
17	do	E	do	Uniform	One prominent fundamental.	Medium	Good (very good except for crack).
18	Wood lath	A-3	Medium gray	Not wholly uniform	Structural only	Rough	Good.

19	do	B-2	Buff	do	Covered with prominent cracks.	Smooth	Very poor.
20	do	B-2	do	do	A number of prominent cracks.	do	Fair (good except for cracks).
21	do	A-3	Light gray	do	Structural only	Rough	Do.
22	do	B-1	Light buff	Nonuniform	Structural and other prominent cracks.	Slightly visible	Poor.
23	do	C-1	do	do	One structural	Smooth	Fair to poor.
24	do	A-3	Dark gray	Not wholly uniform	Structural somewhat visible.	Medium	Good.
25	do	B-1	Buff	do	Number of cracks parallel to lath.	do	Fair.
26	Plaster board	A-1	Light gray	do	Several prominent cracks	do	Fair (good except for cracks).
27	do	A-1	do	do	do	do	Do.
28	do	A-1	do	do	do	do	Do.
29	do	A-1	do	do	do	do	Do.
30	Concrete block	A-1	do	Several large discolored patches.	One crack slightly visible	do	Fair (good except for patches).
31	Terra-cotta tile	A-1	Light gray	Not wholly uniform	None	Slightly visible	Good.
32	do	B-1	Light buff	do	Cracks somewhat visible. Blisters and scaly patches.	Smooth	Poor.
33	do	C-1	do	Nonuniform	Covered with prominent cracks.	do	Very poor.
34	do	D-1	Dark gray	Not wholly uniform	None	Rough	Fair (good except for blotches).
35	do	A-1	Light gray	Discolored patch and nonuniform.	Several cracks somewhat visible.	Slightly visible	Poor (fair except for patch).
36	do	A-2	do	Nonuniform	Several prominent cracks	Medium	Fair.
37	do	G-1	White	Uniform	None	Smooth	Excellent.
38	do	A-1	Dark gray	Uniform except for efflorescence.	do	Rough, especially upper half.	Fair (very good except for efflorescence).
39	Brick	A-1	Light gray	Few prominent spots	do	Slightly visible	Fair (good except for spots).
40	do	B-2	Buff	Nonuniform	do	Smooth	Fair.

TABLE 7—Continued

Panel No.	Base	Stucco	Superficial inspection				
			Color	Uniformity of color	Cracks	Float marks	Appearance
41	Brick (unfinished)						
42	Gypsum block	A-1	Dark gray	Uniform except for efflorescence.	Two prominent cracks	Slightly visible	Fair to poor.
43	do	A-1	do	do	do	do	Fair.
44	do	A-1	Dark and medium gray	Lower half uniformly dark, upper half nonuniform.	Three prominent cracks	Smooth	Lower half fair to good, upper half poor.
45	Monolithic concrete.	A-1	Light gray	Not wholly uniform, somewhat streaked.	None	Rough, somewhat wavy	Fair to good.
46	do	A-1	Dark gray	Nonuniform	do	Rough	Fair.
47	do	A-1	Medium gray	Uniform, slightly streaked and spotted.	do	Smooth, slightly wavy	Good.
48	do	A-1	Dark gray	Not wholly uniform	do	Medium	Very good.
49	do	C-1	Light	Uniform	do	do	Do.
50	do	A-1	Dark gray	Not wholly uniform	do	Rough	Excellent.
51	Bishopric board	A-1	Light gray	Uniform	Numerous prominent cracks.	Smooth	Fair (good except for cracks).
52	do	B-1	Light	Uniform, but shows efflorescence.	Several prominent cracks	do	Do.
53	Terra-cotta tile	A-1	Dark gray	Nonuniform, splotchy	Two slightly visible cracks.	Medium	Poor.
54	Metal lath	A-1	Medium gray	Not wholly uniform	Structural faintly visible	Rough	Fair to good.
55	do	C-2	Light buff	do	Structural	Medium	Fair (good except for cracks).
56	Clinton welded sheathing.	A-4	Dark gray	Nonuniform	None	Rough	Poor.

Panel No.	Base	Stucco	Detailed inspection			
			Cracks	Bond	Structural condition	Remarks
1	Metal lath	A-1	Structural and body. No surface cracks.	Good	Fair	Structural cracks mainly responsible for appearance rating.
2	do	A-1	do	do	do	Do.
3	do	B-2	Structural and body	do	do	Body cracks more vertical than horizontal. Some may follow furring or studs.
4	do	C-1	do	do	do	Do.
5	do	D-2	Structural and body, no surface	do	Fair to good	Body cracks not so wide as in panels 1 and 2.
6	do	D-3	Structural cracks, one small body crack.	do	Good	Panel discolored by cement gun spray from panel 48.
7	do	F-1	Structural and some surface	do	Very good	Efflorescence shows plainly on large section of panel.
8	do	F-2	Structural only	do	Excellent	Panels 7 and 8 braced to counteract effects of shrinkage in sheathing.
9	do	A-2	Structural vertical and horizontal body surface.	do	Fair to poor	Vertical cracks at regular intervals appear to follow furring. At least one horizontal crack follows lap of lath. Such cracks appear to be fundamental.
10	do	A-1	A number of structural and body, some fundamental.	do	Poor	Some fundamental cracks apparently following furring.
11	do	B-2	Structural, body, and fundamental	do	Fair to poor	Do.
12	do	A-1	Some structural and body, few surface	do	Fair to good	Several body cracks at bottom may be fundamental over furring.
13	do	C-1	Numerous body, a few inches apart	do	Very poor	Cracks mostly vertical and horizontal. Some may follow furring and laps.
14	do	G-2	Surface and body slightly visible	do	Very good	Practically no cracks visible 10 feet away on account of color.
15	do	A-1	No cracks	do	Excellent	
16	do	B-1	Some structural, body surface and two fundamental.	Imperfect on right half.	Fair	Apparent efflorescence on right side. Fundamental cracks half height of panel over studs.
17	do	E	Several surface, structural, body, and one fundamental.	Good	do	Fundamental crack over stud.

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TABLE 7—Continued

Panel No.	Base	Stucco	Detailed inspection			
			Cracks	Bond	Structural condition	Remarks
18	Wood lath	A-3	Structural and few body	Good	Good	
19	do	B-2	Structural and numerous large body cracks.	do	Poor	Some of these cracks my be fundamental.
20	do	B-2	Some structural, numerous large body	do	do	Do.
21	do	A-3	Structural, possibly one or two small body.	do	Very good	
22	do	B-1	Some surface and structural. Numerous fundamental and many body.	do	Very poor	Entire panel shows pattern of lath.
23	do	C-1	Structural and two body	do	Very good	Entire panel shows pattern of lath. Discolored by cement gun spray from panel 53.
24	do	A-3	Structural, several body	do	Good	Panel stained by "Parlock" spray from panel 42. Body cracks extend from bottom of panel to height of window sill.
25	do	B-1	Some surface and structural, numerous fundamental and many body.	do	Very poor	Entire panel shows pattern of lath.
26	Plaster board	A-1	Fundamental and body	do	Poor	Fundamental cracks follow joints in plaster board. Body cracks diagonal over surface of boards.
27	do	A-1	Fundamental, body, and surface	do	do	Fundamental cracks follow joints in plaster board. Body cracks diagonal over surface of boards. Some body cracks appear to follow lines of studs. "Parlock" treatment shows no beneficial effect. Felt board slightly wrinkled.
28	do	A-1	do	do	do	Felt board considerably wrinkled, cracked in one place. Chip board in good condition.
29	do	A-1	do	do	do	Felt board very little wrinkled.
30	Concrete block	A-1	Surface cracks over entire panel. Numerous body.	do	Fair	One vertical crack, may be structural.

31	Terra-cotta tile	A-1	Surface and body	Good	Fair to poor	Fine cracks covering entire panel a few inches apart. Do not follow outline of tile.
32	do	B-1	Numerous body, some surface	Top coat loose in spots.	Very poor	Body cracks cover entire panel a few inches apart in all directions.
33	do	C-1	Numerous body	Good	Poor	Do.
34	do	D-1	Slightly visible body cracks	Imperfect	Good	Stucco appears to be separated in spots, but no blistering or cracking apparent.
35	do	A-1	Numerous body, some surface	Good	Fair to poor	Body cracks several inches apart. Upper and lower sections alike.
36	do	A-2	Numerous body and surface	do	Upper half good, lower half fair.	Only surface cracks on upper half. Left half shows efflorescence.
37	do	G-1	Body 8 to 10 inches apart on lower half, two or three on upper half.	do	(See remarks)	Upper half excellent, "parlocked" quarter fair to good, "antihydrine" quarter fair.
38	do	A-1	Numerous body on lower half, none on upper.	do	do	Efflorescence mostly on "antihydrine" quarter. Upper half excellent, lower half fair.
39	Brick	A-1	Surface, over entire panel an inch or two apart.	do	Very good	No difference in sections with and without hair.
40	do	B-2	Numerous surface, several body	Mortar soft and flaking just above water table.	Fair to good	Surface cracks several inches apart cover entire panel.
41	Brick (unfinished)					
42	Gypsum block	A-1	Two body, some surface	Good	Good	One crack appears deep and may be fundamental.
43	do	A-1	Two large body	Sounds hollow in lower right corner.	do	Cracks may be fundamental.
44	do	A-1	One or two structural, numerous body, especially in lower half.	Poor in several spots.	Upper half poor, lower half very poor.	
45	Monolithic concrete	A-1	Numerous body and surface	Good	Fair	Very fine cracks running in all directions and close together.
46	do	A-1	Surface, one small body	do	Very good	Surface cracks faintly visible over entire panel.
47	do	A-1	Surface only	do	do	One small blister noted.
48	do	A-1	Numerous surface only	do	do	Surface cracks particularly numerous in lower section.

TABLE 7—Continued.

Panel No.	Base	Stucco	Detailed inspection			
			Cracks	Bond	Structural condition	Remarks
49	Monolithe concrete.	C-1...	Fine body only	Good	Good	Cracks mostly vertical and horizontal and short. One or two run across panel.
50	.....do.....	A-1...	A number of surface only	.....do.....	Excellent	Cracks only faintly visible.
51	Bishopric board....	A-1...	Structural, fundamental, and body	.....do.....	Poor	Some body cracks appear to penetrate all coats. Most cracks do not occur at joints. Right half appears to have bulged outward. Majority of cracks parallel to lath.
52	.....do.....	B-1...	Two structural, some fundamental and surface, many body.	.....do.....	Very poor	Most cracks do not appear at joints. Bottom of panel flaking, apparently due to freezing.
53	Terra-cotta tile.....	A-1...	Numerous surface and some body	.....do.....	Fair	Surface cracks 8 to 10 inches apart over entire panel.
54	Metal lath.....	A-1...	Structural only	.....do.....	Excellent	
55	.....do.....	C-2...	Structural and body	.....do.....	Fair to good	Body cracks at regular intervals along bottom of panel indicate that they may follow furring.
56	Clinton welded sheathing.	A-4...	None	.....do.....	Excellent	Surface partly scaly and nonuniform due to freezing.

From this table it will be noted that the following panels have a rating of "good" or better both in appearance and structural condition: Nos. 8, 14, 15, 18, 24, upper half of 37. 47, 48, 49, and 50. It should be borne in mind, however, that the type of finish adopted for the test panels is designed to bring out the defects of the stuccos more prominently than the rougher finishes, and wherever defects of finish or structural defects have marred the general appearance, too great weight should not be given to the appearance ratings. Thus a number of additional panels will be found that are good, very good, or excellent structurally, but are not in the satisfactory class for some cause which it is believed can be easily remedied. Panels which come into this class are: Nos. 6, 7, 21. 34, upper half of 36, 38, 39, 46, 54, and 56. Of these panels, Nos. 6 and 21 show structural cracks, which are attributed to shrinkage of sheathing. Similar cracks have occurred on all panels of similar construction, but have not occurred on the panels over frame construction where sheathing was not used. In sheathing the second-story walls on the east and west side the boards were laid diagonally in one direction, which appears to have resulted in a rack upon the frame of all the panels so sheathed. It is believed that if adjacent panels had been sheathed in opposite directions, the structural cracks would have been largely eliminated. Panels 34, 39, 46, 54, and 56 have a reduced rating mainly on account of the method of finishing. The condition of these panels, and a number of others, indicates positively that a more even and pleasing finish can be obtained if the water content of the finish coat is kept under control, and the floating is done in such manner as to bring out the grain and, in so far as possible, to keep the fine cementing material from coming to the surface. Under these conditions surface cracks are much less likely to form, and, if they do occur to some extent, are much less visible. Panel 56 deserves special mention in that it is structurally perfect but on account of freezing of the finish coat a few hours after application has a thin scaling film over a considerable portion of the surface. Panels 7, 36, and 38 are discounted for efflorescence which is especially conspicuous on a smooth finish.

It does not seem desirable at the present time to go into further classification of the panels according to their rating, nor to draw general conclusions from many of the numerous comparisons which might be made. Mention should be made, however, of an attempt to determine the effect of the waterproofing compounds used in panels 7 and 8 in preventing absorption of water in comparison with stuccos of similar composition. The test was made by

wetting down panels 5, 6, 7, 8, 9, and 10 on the east side of the building three afternoons, the water being applied with a hose to each panel five alternate minutes and timing the rate of drying. An attempt was made to note the time when the first dry spot appeared, when approximately one-half the panel appeared dry, and when the panel was completely dry (except for water held in cracks and along the edges). From these and other observations it is now believed that the apparent rate of drying depends, perhaps largely, upon other factors than the composition of the stuccos and the assumption that the amount of absorption is indicated by the rate of drying under similar exposure conditions is not wholly justified. Nevertheless, a stucco which dries quickly or shows little contrast between damp and dry areas is desirable, and the following table of observations shows that the six panels differ considerably in this respect:

TABLE 8

Observations on the Rate of Drying of Waterproofed and Unwaterproofed Stuccos

Panel No.	Interval in minutes from end of wetting to—												Remarks
	First dry spot				One-half dry				Completely dry				
	May 22	May 27	May 29	Mean	May 22	May 27	May 29	Mean	May 22	May 27	May 29	Mean	
5....	15	14	17	15	71	66	90	76	(a)	(a)	(a)	180	Change from wet to dry gradual; damp areas merge into dry without distinct lines of separation. On account of slow rate of drying, time when completely dry not determined.
6....	13	10	15	13	28	30	35	31	103	80	(b)	92	Dries out gradually, showing blotchy appearance when partially dry. A number of round spots 2 or 3 inches in diameter appear damp long after remainder of panel appears dry.
7....	12	15	15	14	24	26	27	26	60	55	66	60	Contrast between wet and dry areas sharply defined. Appears very dark when wet. Two or three very small spots appear damp long after remainder of panel appears dry.
8....	10	9	10	10	24	22	23	23	59	38	42	46	Contrast between wet and dry areas even greater than in panel 7, otherwise the same remarks apply.
9....	9	12	13	11	23	23	35	27	84	71	(b)	78	Difficult to determine rate of drying on account of network of cracks, many of which show damp areas 2 or 3 inches wide long after remainder of panel appears dry.
10....	5	5	6	5	18	19	18	18	73	60	59	64	Same remarks apply as for panel 9, but wet areas at cracks are not so wide. This panel also shows a small slow drying area left of window.

[a] Estimated. [b] Thundershower May 29 prevented completion of observations on panels 6 and 9.

The weather conditions at the time the foregoing tests were made were as follows:

May 22, sky overcast, temperature 68, relative humidity 41, moderate gusty breeze.

May 27, sunny, some haze, temperature 85, relative humidity 46, moderate breeze.

May 29, sunny, some haze, temperature 85, relative humidity 50 to 60, sun obscured by approaching clouds 2.50 p. m., shower at 3 p. m.

The results of the tests are inconclusive. Panels 8, 7, and 10 show more rapid drying than panels 5 and 6, but there is a very great difference between the last two which is not easily explained. Similar unaccountable differences have been noted in other panels; for example, panel 50, directly under panel 5, is a very quick-drying panel, whereas panel 47, directly under panel 8, dries very slowly. These two panels have the same stuccos and similar bases.

IX. OBSERVATIONS

It is believed that general conclusions based on the present condition of the test panels are premature, and that further developments should be awaited and the results of an extensive field investigation should be available before recommendations for stucco construction are attempted. However, those especially interested in the subject may obtain much suggestive information by studying the tables containing the description of the forms of construction and present condition of the panels. Attention is called below to certain observations in connection with the test structure which are sufficiently interesting and important to warrant special mention in this first progress report. These are as follows:

1. No structural cracks have yet appeared in the test structure which can certainly be attributed to settlement. Those which are classed as structural cracks occur almost entirely in the sheathed panels of the second story, and the evidence indicates that these cracks are due to an improper method of sheathing.

2. Examination of the back of the panels in Groups I and II shows that where hair was used in the first coat the lath is generally well embedded, though where hair was omitted the lath is more completely embedded.

3. There is no apparent difference in the condition of the panels in which coated and uncoated wood lath was used which can be attributed to the treatment of the lath.

4. No fundamental cracks have been certainly identified over joints in tile, brick, concrete block, or gypsum block.

5. The lighter shades of stucco show cracks less prominently after wetting than the darker shades.

6. The stuccos applied directly on monolithic concrete bases have without exception been satisfactory to date.

7. The prominence which the smooth sand-float finish gives to fine cracks, unevenness of texture, blotches, and other small defects suggests the advisability of finishing stuccos with rougher surfaces, such as the "rough-cast" or "pebble-dash" finishes.

X. REPORT OF EXPERT PLASTERERS, MESSRS. EARLEY, BAGNALL, AND HUMPHREYS, ON CONDITION OF STUCCO PANELS APRIL 4 AND 5, 1916

We have classified cracking under three headings:

(1) Structural cracks, which probably extend through all coats, caused by movements in the building, appearing generally at or near window and door openings.

(2) Map cracks, which are secondary cracks, extend through one or more coats, and are probably due in some cases to over-rich mixtures, in others to movements in the stucco itself. All of these secondary cracks are termed map cracks without regard to their direction or pattern. There were many cracks of this type which we could not satisfactorily explain.

(3) Craze cracks. Under this head we have considered the very light irregular cracks which seem to be in the surface. We think these cracks are in a thin film of cementing material which is brought to the surface by finishing the stucco when it is too wet.

In this inspection color and texture of the panels were not taken into consideration, the statements being based on the general condition of the panels without regard to the type or quality of finish.

Panel 1.—Good panel except for large structural cracks around window. After wetting: Only structural cracks shown.

Panel 2.—Same remarks as for panel 1.

Panel 3.—Several cracks. Those at bottom of panel appear to be due to weakness over door. After wetting: Map cracked; cracks appear to run in straight lines rather than cross hatched.

Panel 4.—Poor condition, badly cracked, appearance not bad from distance. After wetting: Appears about the same as panel 3.

Panel 5.—Very good panel except for cracks around window. After wetting: A few additional cracks show under window.

Panel 6.—Same remarks as for panel 1.

Panel 7.—Very good condition. Cracks at window corners barely visible from ground. The better condition of panels 7 and 8 attributed to bracing behind. After wetting: Condition the same.

Panel 8.—Same remarks as for panel 7.

Panel 9.—Same remarks as for panel 1.

Panel 10.—Extensively cracked, more so than most of the panels on this side. The fault is believed to be in the base construction, but it is not clear why this panel differs in this respect from similar panels. After wetting: Condition the same.

Panel 11.—Panel looks well, a few very fine cracks. After wetting: Considerably map cracked.

Panel 12.—Same remarks as for panel 1.

Panel 13.—Very poor condition on lower half, upper half better. The mortar is probably too rich and floated too soon. After wetting: A few more cracks visible.

Panel 14.—Excellent condition. After wetting: Considerable crazing, probably due to wet finish.

Panel 15.—Excellent condition. After wetting: Condition the same.

Panel 16.—Panel good. Frost appears to have caught a section on right hand side. After wetting: Shows map cracks.

Panel 17.—Generally good panel except lower-left quarter which has crack over stud and several hair cracks probably due to floating too soon. After wetting: Considerable map cracking.

Panel 18.—Same remarks as for panel 1.

Panel 19.—Poor condition, badly cracked, possibly due to shrinkage (long cracks), also too rich. Condition confirmed with wetting.

Panel 20.—Same remarks as for panel 19.

Panel 21.—Same remarks as for panel 1.

Panel 22.—Panel good except that it shows pattern of lath. After wetting: Same condition, more cracks visible. Position of these cracks indicates that many were caused by the base.

Panel 23.—Panel good except that it shows pattern of lath. After wetting: Condition good, cracks at window.

Panel 24.—Same remarks as for panel 1. After wetting: Shows a few structural and map cracks.

Panel 25.—Appears well from a distance. After wetting: Badly cracked. Position of these cracks indicates that many were caused by the base.

Panel 26.—Panel good except for horizontal and vertical cracks. After wetting: Little or no map cracking or crazing. Position of structural cracks indicates that the cause is the base.

Panel 27.—Same remarks as for panel 26.

Panel 28.—Same remarks as for panel 26.

Panel 29.—Same remarks as for panel 26.

Panel 30.—Very good panel aside from blotchy appearance. Apparent shrinkage cracks below window. After wetting: Badly crazed and map cracked. Blotchy appearance probably caused by uneven drying; cement blocks probably held more water in one place than another.

Panel 31.—Badly map cracked. Panel hard, good bond. Left half o. k. in appearance, rather better than right half. After wetting: Badly map cracked all over, both sides equally bad. At present time do not think it advisable to assign cause.

Panel 32.—Badly map cracked; appearance bad; caught with frost; mortar too rich. After wetting: Same report as for panel 31, appearance similar to panel 31.

Panel 33.—Very unsatisfactory appearance and condition. Probably too rich mix. Mortar very hard but badly map cracked. Bond good. After wetting: Condition the same.

Panel 34.—Panel very good but peculiar blue-gray color. Bond appears to be broken in places. After wetting: Considerably map cracked.

Panel 35.—Badly cracked, blotchy appearance. Most of cracking appears to be over glazed tile. After wetting: Badly map cracked and crazed. Blotchy condition due to uneven drying construction, probably held more water in one place than another.

Panel 36.—Badly cracked in lower half. Bond good. After wetting: Condition same; map cracked and slightly crazed.

Panel 37.—Very good panel. After wetting: Considerably crazed and map cracked. Very difficult to make examination owing to extreme whiteness of finish. At present time can not notice any difference over the coated and uncoated portions of the base.

Panel 38.—Very good panel, bond perfect. After wetting: Badly map cracked. At present time can not notice any difference over the coated and uncoated portions of the base.

Panel 39.—Panel craze cracked. Two members of the committee think more sand in the stucco would have been better. After wetting: Badly crazed, probably due to finishing too wet.

Panel 40.—Very good panel. After wetting: Showed considerable map cracking.

Panel 41.—Unfinished.

Panel 42.—Good panel except for large crack above and below window, probably due to contraction. After wetting: Structural and craze cracks visible.

Panel 43.—Good panel except for two large cracks below window. After wetting: Condition same.

Panel 44.—Top coat on lower half cracked and bond poor in places. Upper half bond appears good. After wetting: Showed map cracks and crazing.

Panel 45.—Good panel. Probably finished too soon for good surface. Too much cement worked to top. Bond good. After wetting: Badly crazed.

Panel 46.—Good panel. Slightly craze cracked along water table, probably due to heavy coat. Good bond. After wetting: Badly crazed, appears to have been finished too wet.

Panel 47.—Good panel, good bond. Probably finished too soon for good surface. After wetting: Badly crazed.

Panel 48.—Fairly good panel except for considerable map cracking just above the water table. This cracking more extensive than on the two adjacent panels (46 and 45), perhaps due to richer mix resulting from gun application. Good bond. One member of committee expressed the opinion that the craze cracking is more probably due to too much cement on the finished surface than to too rich a mix. After wetting: Same condition.

Panel 49.—Good panel, slightly cracked at bottom. May be due to slightly heavy coat and floating too soon. After wetting: More map cracks show but are very short and in straight lines.

Panel 50.—Excellent condition, good bond. After wetting: Condition same (slightly crazed on bottom above water table).

Panel 51.—Appearance bad. Panel contains several large cracks but is not map cracked. After wetting: Same condition.

Panel 52.—Several large cracks, appearance bad. Stucco flaked off under door sill, apparently due to frost. Dampness appears to be working up from water table. After wetting: Badly map cracked, other conditions the same.

Panel 53.—Good panel aside from color. Fine cracks discernible. After wetting: Blotches from resurfacing; map cracked and crazed.

Panel 54.—Same remarks as for panel 1.

Panel 55.—Appearance good except for several cracks radiating from window. After wetting: Condition similar, a few cracks showed.

Panel 56.—Appears well except for flaked surface due to frost. After wetting: Condition same.

XI. SUPPLEMENTARY REMARKS ON THE CONDITION OF THE TEST PANELS DECEMBER 8, 1916

Owing to the delay in publication of this paper it has been deemed advisable to add a statement covering the more obvious developments in the test panels since the April, 1916, inspection. The following remarks are based on an examination of the panels

December 8, 1916, made by the Bureau, but not with sufficient thoroughness to warrant an entire revision of the April ratings.

Panel 1.—Cracks more prominent and noticeably more numerous.

Panel 2.—Cracks more prominent and decidedly more extensive than in panel 1. Condition of this panel now approximates that of panel 9.

Panel 3.—No decided change.

Panel 4.—No decided change.

Panel 5.—No decided change. This panel is now in better shape than panels 1 and 2.

Panel 6.—No decided change.

Panel 7.—Structural cracks larger and more prominent.

Panel 8.—Structural cracks larger and more prominent.

Panel 9.—More extensively cracked. Condition poor.

Panel 10.—More extensively cracked. Condition very poor.

Panel 11.—No decided change.

Panel 12.—A number of vertical body or fundamental cracks have developed, together with many surface cracks. Condition fair to poor.

Panel 13.—No decided change.

Panel 14.—Surface and apparently a number of fine body cracks cover nearly entire panel. These cracks are barely perceptible without wetting the panel.

Panel 15.—No change.

Panel 16.—More extensive body cracking.

Panel 17.—More extensive body and surface cracking.

Panel 18.—A number of cracks parallel to lath, visible without wetting. Considerable development of body and surface cracks, especially on lower half.

Panel 19.—No decided change. Shows pattern of lath after wetting.

Panel 20.—No decided change.

Panel 21.—Two or three prominent cracks parallel to lath visible without wetting. Five long cracks of this type showed after wetting.

Panel 22.—No decided change.

Panel 23.—No decided change.

Panel 24.—No decided change.

Panel 25.—Extensively cracked, both parallel and perpendicular to lath.

Panels 26, 27, 28, 29.—Structural and fundamental cracks more prominent.

Panel 30.—Shows three or four prominent cracks without wetting. Otherwise no decided change.

Panel 31.—Body cracks apparently more numerous. Some are visible without wetting.

Panel 32.—Body cracks apparently more numerous. Some are visible without wetting.

Panel 33.—No decided change.

Panel 34.—Body cracks now well distributed over entire panel. These cracks are not readily visible without wetting.

Panel 35.—No decided change.

Panel 36.—Possibly more extensive cracking. No decided change.

Panel 37.—No decided change.

Panel 38.—Cracking more extensive. Numerous body cracks have developed in upper half.

Panel 39.—No decided change.

Panel 40.—Possibly more extensive cracking. No decided change.

Panel 42.—Five prominent cracks. Otherwise no decided change.

Panel 43.—No decided change.

Panel 44. Cracks more numerous and prominent. On lower half stucco is separating and beginning to warp.

Panel 45.—Cracks prominent without wetting. Otherwise no decided change.

Panel 46.—Fine lace work of surface cracks covers entire panel. One large structural (?) crack extending through the concrete wall below window runs down into water table but apparently does not extend through concrete sill.

Panel 47.—Surface cracks form very fine and even lace work pattern over entire panel.

Panel 48.—No decided change.

Panel 49.—Fine cracks appear to be more numerous. No decided change.

Panel 50.—No decided change.

Panel 51.—Cracks wider and more conspicuous.

Panel 52.—Cracks appear to be more prominent and disintegration of coating at bottom of panel progressive.

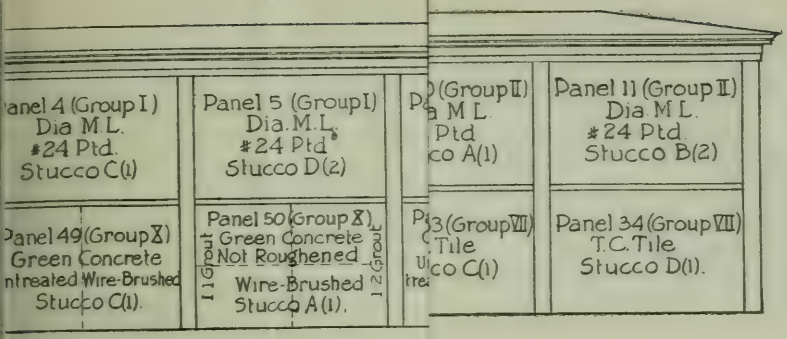
Panel 53.—No decided change.

Panel 54.—No decided change.

Panel 55.—Possibly more extensive body cracking.

Panel 56.—One fine crack, possibly structural, has developed, extending from upper right corner of window to cornice. No other change apparent.

WASHINGTON, July 13, 1916.



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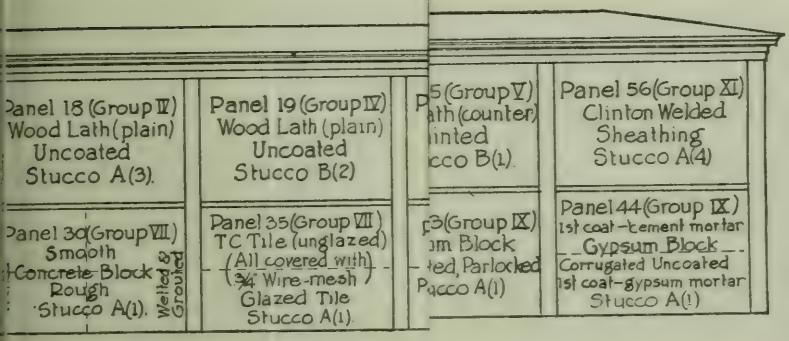
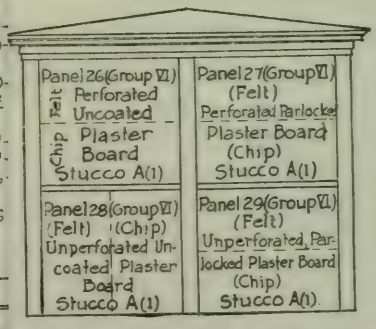


V

STUCCOS

1 cement, 0.1 mg lime, 3 sand
0.75 " 0.25 " " 3 "
1 " 0.1 ca lime, 3 "
1 " 0.1 mg " 4 "
0.25 " 0.75 ca " 3 " (1st coat)
0.25 " 0.75 " " 4 " (2d & 3rd coats)
0.25 " 0.75 mg " 3 " (1st coat)
0.25 " 0.75 " " 4 " (2d & 3rd coats)
1 "Alca" lime, 3.5 sand (1st coat)
1 " " 4 " (2d & 3rd coats)
0.25 cement, 0.75 "Alca" lime, 3.5 sand (1st coat)
0.25 " 0.75 " " 4 " (2d & 3rd coats)



PANEL PLAN-
BUREAU OF ST

SOUTH ELEVATION

F

Panel 1 (Group I) Dia M.L. #26 Galv. bef exp. / #26 Galv after exp Stucco A(1)	Panel 2 (Group I) Dia M.L. #24 Ptd Stucco A(1)	Panel 3 (Group I) Dia M.L. #24 Ptd. Stucco B(2)	Panel 4 (Group I) Dia M.L. #24 Ptd. Stucco C(1)	Panel 5 (Group I) Dia. M.L. #24 Ptd. Stucco D(2)	Panel 55 (Group I) Dia. M.L. #24 Ptd. Stucco C(2)	Panel 6 (Group I) Dia M.L. #24 Ptd. Stucco D(3)	Panel 7 (Group I) Dia. M.L. #24 Ptd. Stucco F(1)	Panel 8 (Group I) Dia M.L. #24 Ptd. Stucco F(2)	Panel 9 (Group I) Wire Lath #20 Galv after woven Stucco A(2)	Panel 10 (Group II) Dia M.L. #24 Ptd Stucco A(1)	Panel 11 (Group II) Dia M.L. #24 Ptd Stucco B(2)
Panel 31 (Group VII) (Haired) T.C. Tile (Unhaired) Stucco A(1).	Panel 32 (Group VII) T.C. Tile Stucco B(1)	Panel 51 (Group XI) Bishopric Board (Creosoted) Lath / (Plain) Lath Stucco A(1).	Panel 49 (Group X) Green Concrete Untreated Wire-Brushed Stucco C(1).	1/2 Grout. Panel 50 (Group X) Green Concrete Not Roughened 1/2 Grout. Wire-Brushed Stucco A(1).	Panel 46 (Group X) Green Concrete Un-treated Grouted Only / Wire Brushed Only / Wire Brushed & Grouted Stucco A(1).	Panel 48 (Group X) Dry Concrete Cement Gun Stucco A(1).	Panel 45 (Group X) Dry Concrete Smooth, Parlocked Stucco A(1).	Panel 47 (Group X) Dry Concrete Muriatic Acid / Picked / Acetic Acid Stucco A(1).	Panel 52 (Group XI) Bishopric Board (Creosoted) Lath / (Plain) Lath Stucco B(1).	Panel 33 (Group VII) T.C. Tile Stucco C(1)	Panel 34 (Group VII) T.C. Tile Stucco D(1)

EAST ELEVATION

Panel 12 (Group II) Wire Lath #20 Galv after woven Stucco A(1).	Panel 13 (Group II) Dia. M.L. #26 Galv. bef exp. / #26 Galv after exp. Limestone Screenings Stucco C(1).	Panel 54 (Group II) Dia M.L. #24 Ptd. Cement Gun Stucco A(1)	Panel 18 (Group IV) Wood Lath (plain) Uncoated Stucco A(3).	Panel 19 (Group IV) Wood Lath (plain) Uncoated Stucco B(2)	Panel 20 (Group IV) Wood Lath (plain) Painted Stucco B(2).	Panel 21 (Group V) Wood Lath (counter) Uncoated Stucco A(3).	Panel 22 (Group V) Wood Lath (counter) Uncoated Stucco B(1)	Panel 23 (Group V) Wood Lath (counter) Uncoated Stucco C(1)	Panel 24 (Group V) Wood Lath (counter) Painted Stucco A(3)	Panel 25 (Group V) Wood Lath (counter) Painted Stucco B(1)	Panel 56 (Group XI) Clinton Welded Sheathing Stucco A(4)
Panel 39 (Group VIII) (Haired) Brick (Unhaired) Stucco A(1).	Panel 40 (Group VIII) Brick Stucco B(2)	Panel 41 (Group VIII) Painted Brick Bituminous Bond(a) / Bituminous Bond(b) Stucco A(1).	Weld. Wire Mesh Panel 30 (Group VII) Smooth Concrete Block Rough Stucco A(1). Weld. Wire Mesh Grout.	Panel 35 (Group VII) TC Tile (unglazed) (All covered with 3/4 Wire-mesh) Glazed Tile Stucco A(1).	Panel 36 (Group VII) Uncoated T.C. Tile Parlocked / Anti-hydrine Stucco A(2)	Panel 37 (Group VII) Uncoated T.C. Tile Parlocked / Anti-hydrine Stucco G(1).	Panel 38 (Group VII) Uncoated Glazed Tile Parlocked / Anti-hydrine Stucco A(1)	Panel 53 (Group VII) T.C. Tile Cement Gun Stucco A(1).	Panel 42 (Group IX) Gypsum Block Smooth, Parlocked Stucco A(1)	Panel 43 (Group IX) Gypsum Block Corrugated, Parlocked Stucco A(1)	Panel 44 (Group IX) 1st coat—Cement mortar / Gypsum Block / Corrugated Uncoated / 1st coat—gypsum mortar Stucco A(1)

WEST ELEVATION

Panel 14 (Group III) Ribbed M.L. #27 Ptd. Stucco G(2)	Panel 15 (Group III) Ribbed M.L. #27 Ptd. Stucco A(1)
Panel 16 (Group III) Ribbed M.L. #27 Ptd. Stucco B(1)	Panel 17 (Group III) Wire Lath #20 Galv after Stucco E

NORTH ELEVATION

STUCCOS

A-1: (parts by weight) 1 cement, 0.1 mg lime, 3 sand
A-2: " " " 0.75 " 0.25 " " 3 "
A-3: " " " 1 " 0.1 ca lime, 3 "
A-4: " " " 1 " 0.1 mg " 4 "
B-1: " " " 0.25 " 0.75 ca " 3 " (1st coat)
" " " 0.25 " 0.75 " " 4 " (2d & 3rd coats)
B-2: " " " 0.25 " 0.75 mg " 3 " (1st coat)
" " " 0.25 " 0.75 " " 4 " (2d & 3rd coats)
C-1: " " " 1 "Alca" lime, 3.5 sand (1st coat)
" " " 1 " " 4 " (2d & 3rd coats)
C-2: " " " 0.25 cement, 0.75 "Alca" lime, 3.5 sand (1st coat)
" " " 0.25 " 0.75 " " 4 " (2d & 3rd coats)

STUCCOS (continued)

D-1: (parts by weight) 1 cement 2.5 sand
D-2: " " " 1 " 2 " (1st coat)
" " " 1 " 3 " (2d & 3rd coats)
D-3: " " " 1 " 3 "
E : " " " 0.5 " 0.5 mg lime, 3 sand (1st coat)
" " " 0.5 " 0.5 " " 4 " (2d & 3rd coats)
F-1: " " " 1 " 0.02 Medusa WP, 3 sand
F-2: " " " 1 " 0.09 Impervite WP, 3 "
G-1 " " " 1 " 0.3 mg lime, 3 sand (1st coat)
" " " 1 white cement, 0.1 mg lime, 2 white sand (2d coat)
G-2: " " " 1 cement, 0.1 mg lime, 3 sand (1st & 2d coats)
" " " 1 white cement, 0.1 mg lime, 3 limestone screenings (3rd coat)

KEY TO ABBREVIATIONS

"Dia M.L." = Diamond mesh metal lath
"Galv bef exp" = Galvanized before expansion
"Ptd" = painted
"T.C. Tile" = Terra Cotta Tile (hollow tile)
"#20" etc = 20 gauge, etc.
"Plain" and "Counter" (wood lath panels) = plain lathing and counter lathing
"Felt" and "Chip" (plaster board panels) = felt surface and chip surface
"Mg lime" = high magnesium hydrated lime
"Ca lime" = high calcium hydrated lime
"W.P." = water-proofing compound

Panel 26 (Group VI) Perforated Uncoated Plaster Board Stucco A(1)	Panel 27 (Group VI) (Felt) Perforated Parlocked Plaster Board (Chip) Stucco A(1)
Panel 28 (Group VI) (Felt) (Chip) Unperforated Uncoated Plaster Board Stucco A(1)	Panel 29 (Group VI) (Felt) Unperforated Parlocked Plaster Board (Chip) Stucco A(1)

SOUTH ELEVATION

PANEL PLAN—STUCCO TEST BUILDING
BUREAU OF STANDARDS—WASHINGTON, D. C.

FIG. 35.—*Panel plan of stucco test building*

DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 71

EFFECT OF CERTAIN PIGMENTS ON LINSEED OIL

BY

E. W. BOUGHTON, Associate Chemist

Bureau of Standards

ISSUED APRIL 13, 1916

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

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[Continued on page 3 of cover]

DEPARTMENT OF COMMERCE

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EFFECT OF CERTAIN PIGMENTS ON LINSEED OIL

By E. W. Boughton

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The action of linseed oil fatty acids on white lead and white zinc	10
The relative effects of certain pigments on the oxidation of linseed oil in paint films	11
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PURPOSE OF THE INVESTIGATION

Since white lead, as supplied to painters and paint dealers, is almost always ground to a paste with raw linseed oil, it seemed desirable to determine whether or not the constants of the oil in the paste are materially changed during storage. Furthermore it seemed desirable to obtain some numerical data regarding the extent to which certain pigments combine with linseed oil during the drying process, and also to make some experiments with drying paint films to determine the relative effects of different pigments on the rate of oxidation of the oil.

EFFECT OF STORAGE OF WHITE LEAD—LINSEED OIL PASTE

In a previous paper [1] the author showed that when mixtures of linseed oil and various pigments (including white lead) in the proportions of paint ready for use were kept in closed containers for two years only slight changes in the constants of the oil resulted. These results showed that if, in the analysis of such mixtures from closed paint cans, oils were obtained which showed abnormal constants, they should not be considered as pure linseed oils. Hannay [2] stated that there is absolutely no combina-

[1] Circ. 111, Bureau of Chem., Dept. of Agriculture; 1913. This paper contains a review of the literature on the action of pigments on linseed oil in closed containers.

[2] Chemical News, 67, p. 268; 1893.

tion of oil and white lead in a paste during storage in closed containers; that the oil can be completely extracted from the paste; and that the extracted oil contains no lead. Harland [3] disagreed with Hannay and stated that the extracted oil always contains small amounts of lead. Davis and Klein [4] confirmed Harland's statement, and also showed that in the extraction of the oil from the paste very small amounts of oil remain with the pigment. They attribute this to the formation of insoluble lead salts of stearic acid or of oxidized unsaturated acids. In a later paper [5] Klein stated that the formation of the small amount of "organometallic" salt is due to the action of the free fatty acids in the oil on the white lead, and that no saponification of the glycerides occurs. Thompson [6] stated that, while a small amount of lead is dissolved by the oil in a white-lead paste, there is no evidence to show that there is any considerable chemical reaction between the pigment and the oil.

In August, 1913, G. W. Thompson, of the National Lead Co., prepared for the author a quantity of white lead—linseed oil paste. Several friction-top cans, holding 1 pound each, were filled with the paste, and these, together with samples of the oil and dry pigment used, were sent to the author. The results of analyses of oil, pigment, and paste are shown in Table 1.

TABLE 1

Analyses of White Lead, Linseed Oil, and Paste

White lead: [a]		
Specific gravity		6.78
Moisture	per cent	.21
$PbCO_3$	do	71.00
$Pb(OH)_2$	do	28.29
$PbSO_4$	do	.23
$PbSO_3$	do	.05
SiO_2	do	.004
$Al_2O_3+Fe_2O_3$	do	.02
Bi_2O_3	do	.01
CaO	do	.03
MgO	do	.02
Alkalies as Na_2O	do	.06
Acetates as $C_2H_4O_2$	do	.14
Total		100.064
Linseed oil:		
Specific gravity at 15.6/15.6° C		0.936
Refrac. index at 25° C		1.481
Acid number		1.9
Saponification number		190
Iodine number (Hanus)		188
Ash	per cent	.20
Paste:		
Pigment	per cent	91.9
Oil (by difference)	do	8.1

[a] Analysis by F. W. Smither.

The oil was divided into several 100 cc samples and kept in stoppered bottles. With each examination of the oil from the

[3] Chemical News, 67, p. 301; 1893.

[4] J. Soc. Chem. Ind., 26, p. 848; 1907.

[5] A paper read before the Paint and Varnish Society of England, December, 1913; published as Lab. Bull, National Lead Co., February, 1914.

[6] Drugs, Oils, and Paints, 30, p. 375; 1915.

paste a simultaneous examination of one of these samples was made. These examinations were made at varying intervals during a period of two and one-half years, the oil in the paste being extracted with ether, recovered, and freed from the last traces of solvent by heating in carbon dioxide at 105–110° C. The results of the analyses, as given in Table 2, show that no material changes in the constants of the oil had occurred during 25 months. It will be noted that the percentage of ash obtained from the oil extracted from the paste was less, in every analysis but the last, than that from the oil alone, although the former contained lead. This diminution of yield of ash by mixing an oil with a pigment is a common occurrence and may be explained by the removal of calcium phosphate from the oil. The experiment is being continued.

TABLE 2

Analyses of Raw Linseed Oil and Oil from Paste

	Time after grinding									
	Five days		Five months		Ten months		Twenty months		Twenty-five months [a]	
	Oil alone (original oil)	Oil from paste	Oil alone	Oil from paste	Oil alone	Oil from paste	Oil alone	Oil from paste	Oil alone	Oil from paste
Specific gravity at 15.6/15.6° C.	0.936	0.937	0.936	0.937	0.936	0.937	0.936	0.937	0.936	0.937
Acid number	1.9	1.6	2.1	1.3	2.0	1.4	2.3	1.5	2.1	1.7
Saponification number	190	190	191	189	192	192	189	189	189	190
Iodine number (Hanus)	188	187	189	189	189	190	191	190	188	188
Ash (per cent)	0.20	0.19	0.20	0.16	0.19	0.14	0.20	0.19	0.18	0.19
Iodine number of fatty acids (Hanus)	.....	.....	195	196	197	196	196	196	194	194
Refr. index of fatty acids at 25° C.	1.471	1.471	1.471	1.471	1.471	1.471	1.471	1.471	1.471	1.471

[a] Subsequent to the preparation of this paper analyses were made after the samples had been kept for 31 months. The figures obtained were all within experimental error of those given in the columns under the heading "25 months," with the exception that the acid number of the "oil alone" was 3.0.

EFFECT OF STORAGE OF MIXTURES OF LINSEED OIL AND VARIOUS PIGMENTS IN PARTIALLY FILLED CONTAINERS

At the completion of the experiments by the author [7] on the action of pigments on linseed oil (see p. 1) the jars containing the remainder of the paints were closed and allowed to stand for 1 year in a closet having a glass door where the light was dim

[7] Loc. cit.

and diffused. The jars were of glass, having a square bottom 2 by 2 inches and rectangular sides 2 by 6 inches, and were approximately one-third filled. The oil was then extracted by ether, recovered, and examined. The results of the examinations, as given in Table 3, show that considerable change had taken place in the oil, except in the zinc yellow, chrome yellow, and artificial graphite paints. White lead and white zinc were the only pigments that caused a large increase in the yield of ash from the oil.

TABLE 3

Constants of Oils Recovered from Pigment—Oil Mixtures After Storage for one year in Partially Filled Containers

Pigment	Per cent pigment	Per cent oil	Constants of oils			Nature of oils
			Specific gravity at 15.6°/15.6° C	Iodine number (Hanus)	Per cent ash	
White lead [a]	72	28	0.976	145	1.02	Orange red; viscous; skin on surface.
China clay (kaolin)	50	50	.976	138	.18	Bleached; viscous; skin on surface.
Indian red	50	50	.973	144	.13	Orange red; viscous; skin on surface.
Flake graphite	40	60	.964	151	.14	More viscous than original oil.
Magnetic oxide black [b]	46	54	.949	167	.13	Do.
Zinc yellow [c]	45	55	.934	177	.15	Same as original oil.
Chrome yellow [d]	66	34	.934	175	.18	Bleached.
Artificial graphite	42	58	.935	181	.11	Same as original oil.
White zinc [e]	39	61	.969	162	.99	Bleached; viscous; skin on surface.
Chromium oxide green	51	49	.970	153	.06	Orange red; viscous.
Original oil			.934	180	.13	

[a] Basic carbonate of lead.
[b] Mainly $FeCO_3$, Fe_3O_4, and Fe_2O_3.
[c] Zinc potassium chromate, containing excess of ZnO.
[d] Lead chromate, containing small excess of PbO.
[e] Zinc oxide.

EXAMINATION OF OIL EXTRACTED FROM PARTIALLY OXIDIZED FILMS OF PIGMENT—LINSEED OIL MIXTURES

Several investigators, among the recent ones being Olsen and Ratner,[8] Ingle,[9] Gardner,[10] Klein,[11] and Friend,[12] have found that the following changes occur during the drying of linseed oil: oxidation, polymerization, a rise in acid number, and the formation

[8] Proc. Eighth Intern. Cong. Applied Chem., Section Ve; 1912.
[9] J. Soc. Chem. Ind., **32**, p. 639; 1913.
[10] J. Ind. Eng. Chem., **6**, p. 9; 1914.
[11] J. Ind. Eng. Chem., **7**, p. 99; 1915.
[12] Drugs, Oils, and Paints, **30**, p. 50; 1914.

of volatile organic compounds (such as acids and aldehydes) of carbon dioxide and of water. Gardner claimed to have detected carbon monoxide in the vapors from drying paint, but Klein stated that the carbon monoxide detected by Gardner was formed when the latter led the vapors from the paint through fuming sulphuric acid. King,[13] however, detected carbon monoxide in the vapors from drying paint with an apparatus wherein fuming sulphuric acid was not used.

Gardner [14] stated as follows: "On account of its alkaline nature this pigment [white lead] acts on the saponifiable oil in which it is ground, forming lead soaps, which accelerate the chalking of white-lead paint." He also states that white zinc saponifies linseed oil. Gardner mixed 5 portions of raw linseed oil with various pigments and allowed the mixtures to stand in beakers for one month. The oil was then extracted and the ash thereof determined. Some of his results were as follows:

	Per cent ash.
Original oil	0.003
Oil from zinc-oxide mixture	.105
Oil from basic carbonate of lead mixture	.116
Oil from basic sulphate of lead mixture	.033
Oil from red-lead mixture	.211

He states that these results show that the pigments had a "direct saponifying action on the oil." This last statement is open to question, since he obtained yields of ash small enough to have been caused by the action of the free fatty acids on the pigments. Since the mixtures stood in open beakers, the amount of free fatty acids in the oils must have increased during the experiment. If pigments like white lead and white zinc have a "direct saponifying action" on linseed oil, oils extracted from mixtures of these pigments and linseed oil after storage in closed containers should yield large amounts of ash, whereas actually only small amounts are obtained.

Klein [15] stated as follows: "The ultimate composition of a white lead-linseed oil skin has not been investigated with any accuracy and I am unable to state whether, in the process of drying, saponification takes place to any considerable extent with consequent formation of lead linoleate, an interaction indicated by certain writers."

---

[13] J. Ind. Eng. Chem., 7, p. 502; 1915.

[14] Paint Technology and Tests; 1911.

[15] A paper read before the Paint and Varnish Society of England, December, 1913; published as Lab. Bull. of the National Lead Co., February, 1914.

Since no solvent has yet been found which will completely dissolve linoxyn, we have no means of ascertaining the amount of metal which is in combination with the oil in a dried paint film. The following experiments were made to ascertain the amount of metal which is in combination with the oil in that portion of a partially dried film which is still soluble in such solvents as ether and benzene (C_6H_6). White zinc and white lead were the pigments used for the tests, and since these had reacted with linseed oil to an appreciable extent in partially filled containers, it was expected that similar results would be obtained with drying films. In the experiments with raw linseed oil the mixtures were spread on glass in layers thicker than would be made in painting work. When boiled oil was used the mixtures were brushed out to thin films on glass. For control experiments mixtures of barytes and oil were used. After certain intervals the films were removed from the glass and treated with ether (experiment 1, Table 5) or with a mixture of 60 volumes of benzene and 40 volumes of 95 per cent methyl alcohol (experiment 2, Table 5).

The solutions from the original mixtures of oil and pigment were perfectly clear, but the ether solutions from some of the partially oxidized mixtures in the experiments with raw oil were slightly turbid even after centrifuging and filtering. This slight turbidity may have been due to suspended metallic soaps or to pigment particles and therefore the experiments were repeated, using the benzene-methyl alcohol mixture. With this solvent all the solutions obtained were clear or showed only a faint opalescence in a tube 1 inch in diameter. This was accomplished by repeated centrifuging and filtration through a thick, tightly packed layer of filter-paper pulp. The extracted oils from the oxidized mixtures were red and viscous and had an acrid odor. The extracts were freed from the last traces of solvent by heating in carbon dioxide at 110–115° C. The ash of extracts was determined, ignition being finished in a muffle at a dull red heat. In the white lead experiments a small amount of lead may have been volatilized during ignition, so that the ash of the extracts may have contained slightly less lead than was present in the extracts.[16] The constants of the oils used are shown in Table 4. Complete data regarding the experiments and the results obtained are given in Table 5. The mixture of white zinc and raw linseed oil was allowed to dry

[16] A mixture of 0.5 g of white lead, containing 0.392 g of Pb, and 15 g of linseed oil yielded an ash which contained 0.370 g of Pb. No appreciable loss of Zn was noted in a similar experiment with white zinc.

for eight days (two days longer than the white lead mixture), because at the end of six days it did not appear to be as much oxidized as the white lead mixture.

TABLE 4

Constants of Linseed Oil

	Raw oil	Boiled oil
Specific gravity at 15.6/15.6° C	0.934	0.943
Refrac. index at 25° C	1.482	1.480
Acid number	2.7	7.1
Saponification number	190	193
Iodine number (Hanus)	189	181
Ash (per cent)	0.14	[a] 0.52
Unsaponifiable matter (per cent)		1.1
Iodine number of fatty acids (Hanus)	195	186

[a] Contains Pb and Mn.

TABLE 5

Changes in Linseed Oil During Drying with Pigments

Composition of mixtures	Exposure of mixture	Experiment 1			Experiment 2: Benzene-methyl alcohol extract—per cent ash
		Iodine number of fatty acids	Ether extract		
			Acid number	Per cent ash	
White lead,[a] 70 per cent Raw oil, 30 per cent	Original mixture	194	2.3	0.25	0.11
	Two days	132	13.3	.53	.52
	Four days	126	10.7	.66	.84
	Six days	103	17.9	.90	.85
White zinc,[b] 44 per cent Raw oil, 56 per cent	Original mixture	194	3.2	.14	.15
	Two days	193	2.8	.29	.16
	Four days	180	4.1	.63	.17
	Eight days	101	10.9	1.70	2.17
Barytes, 52 per cent Raw oil, 48 per cent	Original mixture	195	2.7	.07	.05
	Two days	191	3.0	.07	.04
	Four days	189	3.5	.08	.06
	Six days	139	9.1	.09	.07
White lead,[a] 70 per cent Boiled oil, 30 per cent	Original mixture	182	8.0	.56	.46
	Six hours	148	10.7	.82	.50
White zinc,[b] 44 per cent Boiled oil, 56 per cent	Original mixture	180	8.3	.64	.73
	Six hours	141	11.2	.95	1.60
Barytes, 52 per cent Boiled oil, 48 per cent	Original mixture	182	8.2	.42	.39
	Six hours	145	11.0	.43	.38

[a] Dutch process. [b] French process; obtained from Dr. Gilbert Rigg, of the New Jersey Zinc Co.

The results of the experiments, as given in Table 5, show that appreciable amounts of lead and zinc have combined with the oil during the drying process. The boiled-oil experiments, of course, more nearly resemble painting practice than those with raw oil, but the iodine number figures show that in the former experiments the films were less oxidized at the end of the exposure than in the latter. The results, as a whole, indicate a greater combination between white zinc and oil than between white lead and oil. In experiment 2 no appreciable increase in ash was obtained after exposure for two and four days of the white zinc-raw linseed oil mixture, but the iodine number of the fatty acids shows that in that time only a very small amount of oxidation had taken place.

As mentioned above, there are no means of ascertaining how much metal is in combination with the oil in a thoroughly dry film. In these experiments the insoluble oxidized oil may have contained a larger percentage of metal combined with oxidized oil than was found in the extracts. If the formation of substances of an acid nature continues for a long time after the film is dry, pigments that are basic in nature, such as white lead and white zinc, probably continue to combine with these acidic compounds. If metallic salts of acids of low molecular weight, such as acetic acid, are formed, decomposition of these salts by the carbon dioxide of the air may occur with the formation of metallic carbonates. Linseed oil films continue to give off volatile matter for a long time, the films losing in weight, and therefore, if the amount of metal in combination with the oxidized oil remains constant, the percentage of combined metal will increase.

Since the composition of thoroughly dry paint films containing such basic pigments as white lead and white zinc is still unknown, assertions that such combination of pigment and oil as occurs is or is not beneficial are not based on established facts. To ascertain with accuracy the amount of metallic soaps in a film and their effect therein would involve a large amount of investigation, requiring better methods of analysis than those now available.

THE ACTION OF LINSEED OIL FATTY ACIDS ON WHITE LEAD AND WHITE ZINC

Thompson [17] stated that white lead is easily ground with linseed oil fatty acids, while white zinc causes a thickening and hardening, presumably owing to the formation of zinc soaps, and that

[17] Drugs, Oils and Paints, 30, p. 375; 1915.

this indicates that the latter pigment has the greater tendency to unite with the fatty acids. According to Thompson, Stas stated that the presence of water aids the combination of white zinc and linseed oil.

To determine whether under certain conditions white zinc combines more readily with linseed oil fatty acids than does white lead, the following experiments were made. One 10 g portion of fatty acids was mixed with 40 g of white lead [18] and another 10 g portion with 33 g of white zinc;[19] thus approximately the same volume of pigment was used in each case. The fatty acids had been previously filtered until clear, but were not heated to remove dissolved water. After one-half hour ether [20] was added to the mixtures and the ash of the ether extracts was determined, the latter having been freed from the last traces of solvent by heating in carbon dioxide at 110–115° C. The ashes obtained were mainly ZnO and PbO, and since the ratio of the combining weights of these two is 1:2.74, the results, as given in Table 6, show that the ether extract from the white zinc mixture contained nearly four times as much fatty anhydride combined as soap as that from the white lead mixture. The mixture of fatty acids and white zinc became quite hot, but no appreciable rise in temperature of the white lead mixture was noted. The experiment confirms Thompson's statement. The ratio of the combining weights of ZnO and PbO should be noted in a consideration of the results given in Table 5.

TABLE 6

Action of Linseed Oil Fatty Acids on White Lead and White Zinc

Pigment	Ash of ether extract (per cent)	
White lead	7.3	(×1=7.3)
White zinc	10.3	(×2.74=28.2)

THE RELATIVE EFFECTS OF CERTAIN PIGMENTS ON THE OXIDATION OF LINSEED OIL IN PAINT FILMS

Although the rate of increase in weight of a drying oil is not an exact measure of the rate of drying, it is roughly proportional to the amount of oxidation that occurs during the increase in weight

[18] Dutch process.

[19] French process.

[20] Lead and zinc soaps, prepared by adding solutions of salts of these metals to solutions of the potassium soaps of linseed oil fatty acids, were found to be readily soluble in ether, benzene, and a benzene-methyl alcohol mixture; 10 g dissolved readily in 100 cc of solvent.

to a maximum, and therefore affords a means of ascertaining the effect of pigments on the oxidation of oil in paint films. According to Friend [21] the time required for an oil to "set" is half that required to obtain the maximum weight.

Toch [22] stated that "when white zinc is mixed with linseed oil and the proper amount of drier, it sets and dries more slowly than white lead." Maire [23] stated that "white lead is a good drier of linseed oil and requires but a small admixture of artificial drier to hasten its drying." Sabin [24] stated that "white lead and

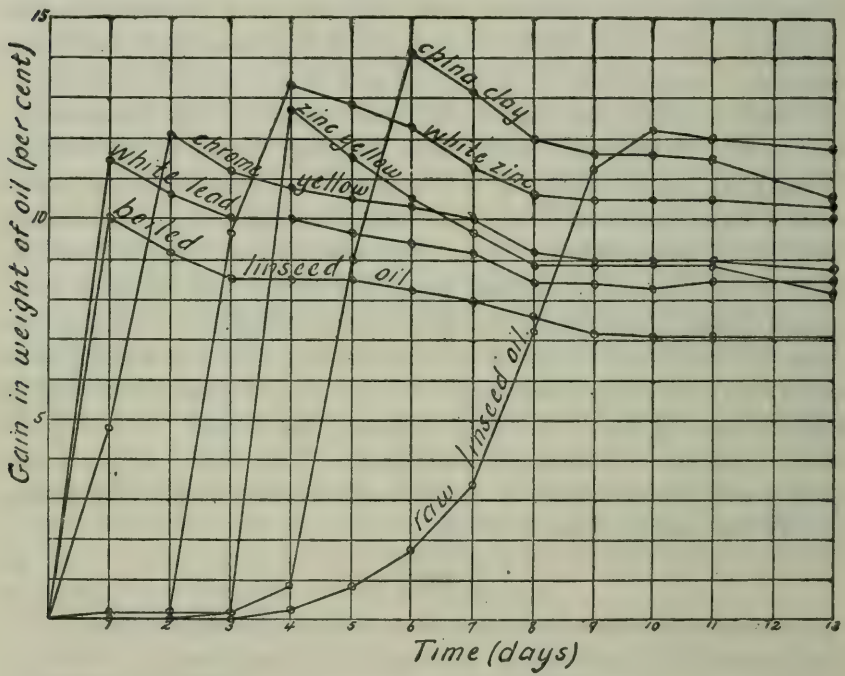

FIG. 1.—*Gain in weight of oil in thin films*

oil do indeed dry more rapidly than oil alone, but so little is this increase that in practice it is not recognized." He made some oxidation experiments with mixtures of various pigments and oil, determining the rate of increase in weight of the oil. His results will be discussed later.

In the present investigation mixtures of raw linseed oil with white lead, white zinc, and china clay were used, and also films of raw and boiled linseed oil. The oils used were those described in Table 4. Further experiments with mixtures of raw linseed

[21] Drugs, Oils, and Paints, 30, p. 50; 1914.
[22] M. Toch, Chemistry and Technology of Mixed Paints; 1907.
[23] Maire, Modern Pigments and Their Vehicles; 1908.
[24] Bottler and Sabin, German and American Varnish Making; 1912.

oil with chrome yellow and zinc yellow were made to ascertain whether or not these pigments would be as "inert" in a drying film as they were in the experiments with paints in partially filled containers. (See Table 3.) The mixtures consisted of approximately one volume of pigment and three volumes of oil, these being the proportions used by Sabin.[25] The composition of each mixture, its specific gravity, and the weight and thickness of film are given in Table 7. The films in experiment 1 were made at approximately the same spreading rate that Sabin used.

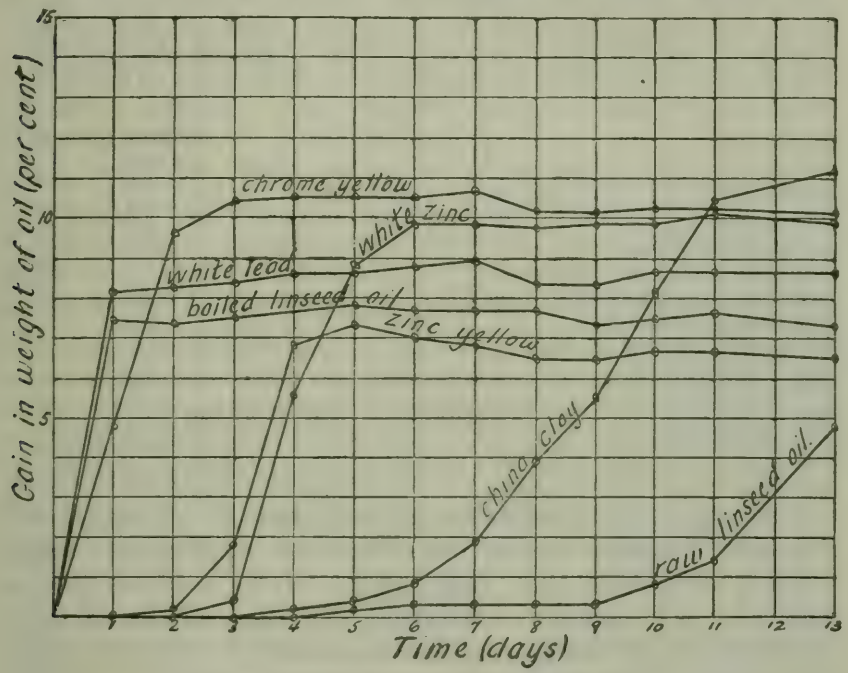

FIG. 2.—*Gain in weight of oil in thick films*

Those in experiment 2 were five times as thick. Owing to the different "oil-taking power" of the different pigments the mixtures varied greatly in viscosity. The films were spread over an area 10 by 10 cm on weighed glass plates and kept in a dust-free cabinet with glass sides and top, there being free access of air. The plates were weighed each day and the gains in weight noted The room temperature during the first seven days was 30–35° C. and during the last six days 25–30° C. The curves representing the increase in weight of the thin films are shown in Fig. 1 and those of the thick films in Fig. 2.

[25] There is an error in the description of Sabin's experiments (German and American Varnish Making, p. 194), the proportions being given as one volume of oil to three volumes of pigment.

The following is a summary of the results with thin films in comparison with Sabin's results. In the present tests white lead greatly accelerated the gain in weight of raw linseed oil, the white-lead curve being very similar to the boiled-oil curve. The white zinc caused no gain in weight during the first two days, but during the third and fourth days had a marked accelerative effect.

TABLE 7

Data on Oils and Mixtures used for Drying Experiments

Composition	Specific gravity	Experiment number	Weight of film	Average thickness of film
			g	mm
Raw linseed oil	0.93	1	0.222	0.023
		2	1.032	.111
Boiled linseed oil	.94	1	.198	.020
		2	.982	.104
White lead, 71 per cent	2.4	1	.886	.037
Raw linseed oil, 29 per cent		2	4.373	.182
White zinc, 66 per cent	2.1	1	.787	.037
Raw linseed oil, 34 per cent		2	3.730	.178
China clay, 48 per cent	1.3	1	.492	.038
Raw linseed oil, 52 per cent		2	2.400	.184
Chrome yellow, 69 per cent	2.2	1	.813	.037
Raw linseed oil, 31 per cent		2	4.100	.186
Zinc yellow, 56 per cent	1.6	1	.574	.036
Raw linseed oil, 44 per cent		2	2.894	.181

China clay had no accelerative effect till the fifth day, but greatly increased oxidation during the fifth and sixth days. Sabin obtained during the early stages of the drying a larger gain in weight for raw oil mixed with China clay than for raw oil with white lead, both having an accelerative effect. His curve representing the gain in weight of raw oil with white zinc was very similar to the curve for raw linseed oil alone. In another experiment Sabin obtained during the early stages of the drying a larger gain in weight for raw linseed oil alone than for raw oil with white lead, raw oil with white zinc, or for boiled linseed oil alone. Both white lead and white zinc caused raw linseed oil to gain in weight more rapidly than boiled linseed oil, the white zinc having the greater accelerative effect.

So many factors—temperature, humidity, thickness of film, etc.—influence the drying of linseed oil that variations in the results obtained by different observers is to be expected, but the small catalytic effect of the driers in Sabin's boiled oil is remarkable. If the boiled oil that he used was the commercial article,

containing lead and manganese, it seems to the author that the gain in weight was abnormally slow, the time required to obtain a maximum weight being eight days. It was certainly slower than the commercial boiled oils that have been thus tested in this laboratory. In the present tests with white lead enough pigment combined with the oil to have a marked catalytic effect on the drying, while in Sabin's experiments this did not occur. In the present tests the accelerative effect of white lead was so much greater than that of China clay that it can hardly be explained except by the catalytic effect of combined lead.

Considering the effect of chrome yellow and zinc yellow in the present tests, the results show that both pigments had an accelerative effect on the oxidation of the oil, that of the chrome yellow being the greater.

In the present tests with films of oil alone, raw linseed oil showed a larger maximum gain in weight than boiled oil. This was the case in many previous tests in this laboratory and in Sabin's experiments. It is worthy of note that of all the oils used in the present tests, that which was mixed with China clay showed the largest maximum gain in weight. This pigment is the only one of those used which could not react chemically with the oil to form metallic soaps which could act as catalyzers.

The pigments in the thick film tests showed approximately the same relationships as accelerators of oxidation that they did in the thin film tests. As would be expected, the gains in weight in the former tests were slower and the maximum gains in weight less.

SUMMARY

The constants, including yield of ash, of raw linseed oil mixed with white lead in paste form showed no material change in 25 months.

Storage, in partially filled containers for one year, of raw linseed oil mixed with white lead and with white zinc (in the proportions of paint ready for use) and exposure of films of such mixtures to air for several days resulted in sufficient combination of oil and pigment to cause the extracted oils to yield amounts of ash that were much larger than those obtained from the oils used to prepare the mixtures. Exposure of films of these pigments mixed with boiled linseed oil to air for six hours caused a small but appreciable combination of oil and pigment.

When white lead and white zinc were mixed with linseed oil fatty acids considerable combination of pigment and fatty acids

occurred. The amount of fatty anhydride combined as zinc soap was nearly four times as great as that combined as lead soap, the calculations being based on the amounts of ash yielded by the ether extracts of the pigment-fatty acids mixtures and the ratio of the combining weights of ZnO and PbO.

The results as a whole indicate that white zinc combines with the free fatty acids of linseed oil more readily than does white lead.

Of the three pigments, white lead, white zinc, and China clay, the former showed the greatest accelerative effect on the oxidation of raw linseed oil in films composed of pigment and oil, while China clay had the least accelerative effect.

When a mixture of raw linseed oil and China clay was kept in a partially filled container for one year the constants of the oil were materially changed, while raw linseed oil with chrome yellow and with zinc yellow under the same conditions showed practically no change. In drying films, however, the accelerative effects of the two yellow pigments on the oxidation of the oil were much greater than that of China clay.

It is obviously unjustifiable to draw from the experimental part of this paper any conclusions regarding the relative values of the different pigments as paint materials. Such conclusions can be properly drawn only from the data afforded by exposure tests with painted panels and from general painting experience.

WASHINGTON, January 4, 1916.

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No. 72

INFLUENCE OF FREQUENCY OF ALTERNATING OR INFREQUENTLY REVERSED CURRENT ON ELECTROLYTIC CORROSION

BY

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and

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Bureau of Standards

ISSUED AUGUST 15, 1916

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

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INFLUENCE OF FREQUENCY OF ALTERNATING OR INFREQUENTLY REVERSED CURRENT ON ELECTROLYTIC CORROSION

By Burton McCollum and G. H. Ahlborn

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INTRODUCTION

This paper describes experimental work done to determine the coefficient of corrosion of iron and lead in soil with varying frequencies of alternating or reversed current with 60 cycles per second as the highest frequency and a two-week period as lowest, some direct-current tests being made as a check on the methods. The results show (1) that a decrease of corrosion occurs with an increase in frequency; (2) that there is a limiting frequency above which practically no corrosion occurs; (3) that the corrosion is practically negligible below a five-minute period; (4) that certain chemicals affect the natural and electrolytic corrosion of the two metals quite differently; (5) that the loss of lead in soil on direct current is about 25 per cent of the theoretical loss; and (6) that alternating or reversed current with as long periods as a day or a week would in the case of iron materially reduce the damage to underground structures.

The importance of these results grows out of the fact that there are large areas in practically every city in which the polarity of the underground pipes reverses with periods ranging from a few seconds to an hour or more, due to the shifting of railway loads. The investigation shows that the corrosion under such conditions is much less than has generally been supposed.

1. DEFINITION

The terms "electrolytic corrosion" and "electrolysis" have been used to designate corrosion caused by the discharge of electric currents which entered the metal from outside sources. In this paper the term "alternating-current electrolysis" applies not only to electrolysis from ordinary alternating currents of commercial frequencies but also to alternating currents of much longer periods, such as several minutes or even a day or longer. Alternating currents of such long periods are very common on portions of underground pipe systems of practically every city, due to the continual shifting of railway loads which causes the pipes within

a large area, commonly called the neutral zone, to continually change their polarity with respect to the earth. In this paper the term "coefficient of corrosion" is frequently used in connection with the corrosion of an anode. This factor is the ratio of the actual corrosion observed to that which would have occurred if all of the electrode reactions determined by Faraday's law had been involved solely in corroding the anode. Thus, if the theoretical corrosion in any case was 100 grams and the observed corrosion 46 grams, the "coefficient of corrosion" would be 0.46. This is sometimes called "efficiency of corrosion."

2. IMPORTANCE AND SCOPE OF THE PRESENT INVESTIGATION

Since most of the electrolysis which occurs is due to stray currents from electric railways, and since only a small percentage of these operate with alternating current, it might seem at first thought that alternating-current electrolysis is of rather infrequent occurrence, and that the problems connected with it do not deserve much attention. However, in addition to the railways which use alternating currents as motive power, such currents often result as an incident of railway operation. These occur not only in the ordinary negative systems of railways mentioned above, as the load shifts from point to point on the track with the movement of the cars, but they occur to a greater extent and in a much larger territory in the case of negative return systems in which insulated negative feeders are used. In such systems the potential differences between pipes and tracks can be greatly reduced, but this is accompanied by a large increase in the area of the so-called neutral zone, in which the polarity of the pipes is continually changing from positive to negative. With certain types of three-wire systems which are now being seriously considered in some places for the prevention of electrolysis, there will be large areas in which the polarity of the pipes will fluctuate between small positive and negative values. It has also been proposed that with the usual type of return that the trolley be made alternately positive and negative on succeeding days or weeks. All of these methods would have the effect of reversing the current flow on underground structures, and the period of the cycle would vary from a few seconds to a day or longer. Moreover, the frequent grounding of 60-cycle lighting circuits permits a certain amount of leakage from those systems, and the corrosion produced, especially in case of accidental grounds on other parts of the system, might be of considerable importance unless it is shown that alternating currents of such frequency do

not give rise to serious corrosion. It is therefore of great practical importance to determine the extent to which periodically reversed currents of these long periods will produce corrosion on subsurface metallic structures.

3. WORK OF PREVIOUS INVESTIGATORS

A number of writers have advanced theories concerning laws governing alternating-current electrolysis and a considerable amount of experimental work has been done with frequencies of 25 to 60 cycles. One writer, discussing the phenomenon from the standpoint of the decomposition of the electrolyte,[1] arrives at certain conclusions: (1) That the amount of chemical decomposition caused by alternating current is less than by direct current; (2) that it is proportional to the electrode current density; (3) that there is a limiting electrode current density below which no decomposition of the electrolyte occurs; (4) that the quantity of corrosion decreases with an increase in the frequency of alternations, and that there is a limiting rapidity of alternation above which there is no decomposition. Conclusions (1) and (4) seem borne out by the experimental work described later.

With reference to the dynamic characteristics of electrolytic cells, several writers have determined by experimental work,[2] chiefly with the oscillograph, that such cells affect the wave form. As one writer states, the chemical polarization in the cell causes it to behave as a variable condenser with a resistance in parallel and in series.

With a very special set of conditions one experimenter [3] has noted an amount of corrosion of the electrodes varying from zero to 35 per cent, with 60-cycle current, and he arrives at the conclusion that the corrosion is practically independent of the current density of the electrodes and temperature; and also that stirring of the solution has no effect. He states that the corrosion does depend on the condition of the electrode surface, but does not attempt to state the principle of this variation.

Experiments of more practical importance to the engineering world were conducted in 1905.[4] Twenty-five-cycle current was impressed on iron and lead pipes buried in soil and it was found

[1] Dr. Guglielmo Mengarini, Electrical World, vol. 18, No. 6, p. 96; Aug. 8, 1891.

[2] D. Ruchinstein. Electrolysis with Alternating Current Dynamic Characteristic of an Electrolytic Cell. Zeitschrift für Electrochemie; Dec. 1, 1909; M. LeBlanc. The emf's of Polarization and Their Measurement by the Oscillograph. Deut. Bunsen Geselschaft, No. 3. Alternating Current Electrolysis Use of Oscillograph in Connection with Polarization. Zeitschrift für Electrochemie, 11, p. 707; 1905.

[3] G. R. White. Alternating Current Electrolysis with Cadmium Electrodes.

[4] S. M. Kintner. Alternating-Current Electrolysis, Electric Journal, vol. 2, p. 668; 1905.

that the corrosion was practically the same as that due to the soil alone. No figures of exact losses are given. Alternating current of 25-cycle frequency was impressed on lead and iron plates in salt solution and direct current was impressed on other plates in a similar electrolyte, and it was found that the loss was negligible for the alternating current and very large for the direct current.

Only a year or so later a large number of tests were conducted with 25-cycle, 60-cycle, and direct current on iron and lead plates.[5] The conditions were varied by using different soils, salts added to soils, varying the temperature and current density. The results show that although there is quite a large variation in the loss with different specimens and that the 25-cycle losses are uniformly greater than the 60-cycle losses, these losses never exceed 1 per cent under normal temperature conditions. The writer notes that some salts—for example, carbonates and alkaline compounds—reduce the electrolytic corrosion of lead plates. He found that an increase of temperature to 40° C increases the corrosion to about 1 per cent. His final conclusions are that alternating-current electrolysis is more irregular than direct-current electrolysis; that nitrates increase corrosion and carbonates generally decrease it, but that the effect is not great enough to be of practical use for protecting lead cables; that lead is more attacked than iron; that the current density does not appreciably affect corrosion except indirectly by increase of temperature; and that the corrosion increases with a decrease in frequency. He attempts to protect lead specimens by making them negative either by connecting them to a zinc plate or with a small direct current, and finds that the loss is considerably less than with the alternating current alone. He finds that a current of 1 per cent of the value of the alternating current is sufficient to give practically complete protection, the corrosion in some instances being less than that due to natural corrosion alone. It will be noted in the above experimental work that the different variables employed, such as current density, chemicals, temperature, etc., do change the action of alternating current, but that in practically no case did the losses exceed 1 per cent. When we consider the large variation of the electrochemical loss produced by direct current under identical conditions, it is evident that differences obtained between 25 and 60 cycle current are practically negligible.

[5] J. L. R. Hayden, Alternating-Current Electrolysis, Trans., A. I. E. E., vol. 26, Part I, p. 201.

Larsen has conducted some experiments on the corrosion effect of reversed currents of very long period using periods of two hours and two days. He found a marked reduction in corrosion, especially on the two-hour period. Prior to the present investigation, however, there have been no published results of tests on reversed currents of periods ranging from a few cycles per second to ten or fifteen minutes per cycle, a range of great practical importance in connection with the electrolysis of underground pipes and cables, as pointed out above.

4. PURPOSE OF THIS PAPER

The data discussed in this paper were obtained as a part of the general investigation of electrolysis conducted by the Bureau of Standards. Its object is not to determine the laws which govern electrolytic corrosion at any one frequency, but to take a standard set of conditions approaching as nearly as possible those existing in practice; that is, wrought iron pipes and lead sheaths imbedded in soil and to determine the corrosion which will occur in the range of frequencies mentioned above, namely, for frequencies ranging from 60 cycles per second to a week or more per cycle. These data will be of material assistance in determining the effectiveness of many of the proposed systems of electrolysis mitigation.

II. DISCUSSION

1. PRELIMINARY EXPERIMENTS ON EFFECT OF CIRCULATION OF ELECTROLYTE

Before beginning the more complete series of tests to determine the effect of change in frequency a number of preliminary experiments were carried out in order to throw light on certain theoretical aspects of the question under consideration. Theoretical considerations led to the belief that the corrosion of frequently reversed currents would be materially increased by rapid circulation of the electrolyte and diminished by conditions which tended to restrict such circulation. If this were true, it was reasoned that in the case of metals buried in soils, in which the circulation of electrolyte is greatly restricted, relatively little corrosion would occur even with periodically reversed currents of long period. Accordingly, a number of experiments were carried out to determine the effect of circulation of the electrolyte on the coefficient of corrosion.

A set of four cells with wrought-iron electrodes and a 1 per cent NaCl solution as the electrolyte were connected in series on 60-cycle current. The electrolyte in cell No. 1 (see Fig. 1) was stirred by a small turbine and in No. 2 the electrolyte was undisturbed; in No. 3 the lectrodes were wrapped with filter paper; and in No. 4 the electrolyte was prevented from mechanical circulation by gelatin. Iron electrodes, which were carefully weighed, were connected in the circuits and the current was maintained at about a half ampere for nearly 200 hours. At the end of the run the electrodes were again weighed and the loss determined by difference from the initial weight. Based on the theoretical loss, which would have been about 100 grams, the coefficients of corrosion (see Table

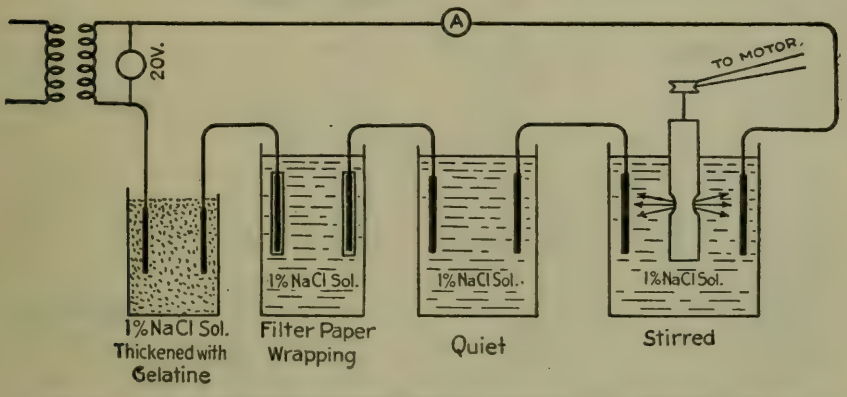

FIG. 1.—*First arrangement for testing effect of convection on electrolytic corrosion*

1) are 0.0034 for the stirred electrolyte; 0.002 in the stationary solution; 0.0009 when protected by filter paper; and 0.0007 in the gelatin. It seems evident that the chemical action is not as reversible when the electrolyte is in motion about the electrodes as when stationary. In order to determine this effect more exactly a single cell was connected, as shown in Fig. 2. Here there were two electrodes with no current impressed to determine the natural corrosion and two serving as current electrodes. One of these was in the electrolyte stirred by the turbine and the other was wrapped in filter paper and buried in sand saturated with the solution. After correcting for the natural corrosion it was found that the coefficient of corrosion was 0.0004 for the upper electrode and 0.0001 for the lower. The results are shown in Table 1.

34822°—16——2

TABLE 1

Effects Due to Variations in the Circulation of the Electrolyte

[Sixty-cycle current; wrought-iron electrodes; 1 per cent NaCl solution electrolyte]

State of electrolyte	Total corrosion	Current	Coefficient of corrosion
	Grams	Amp.-hours	
Stirred	0.344	96	0.0034
Stationary	.202	95	.0020
Filter paper separation	.088	96	.0009
Gelatin	.074	96	.0007
Stirred	.065	160	.0004
Sand saturated	.016	160	.0001

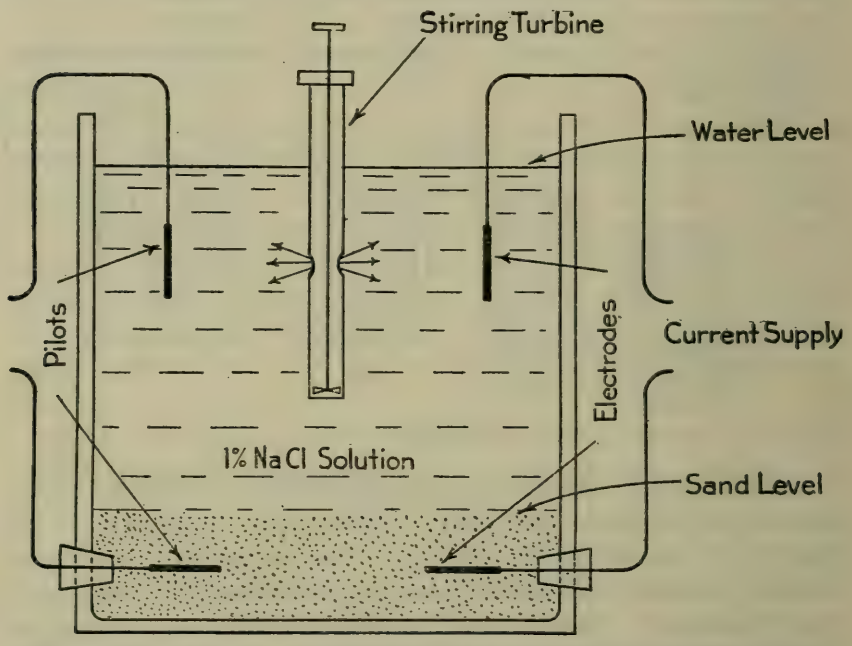

FIG. 2.—*Second arrangement for testing effect of convection on electrolytic corrosion*

The same type of cell was operated on 20-cycle alternating current with the losses as shown in Table 2.

TABLE 2

Effects due to Variation in the Circulation of the Electrolyte

[Twenty-cycle current; wrought-iron electrodes; 1 per cent NaCl solution electrolyte]

State of electrolyte	Total corrosion	Current	Coefficient of corrosion
	Grams	Amp.-hrs.	
Stirred	0.079	144.4	0.0005
Sand saturated	.009	144.4	.00006

It will be noted that the corrosion is substantially negligible as in the case of 60 cycles under the same conditions. The same type of cell was placed in a direct-current circuit, which was reversed every 24 hours. As might be expected, the losses were very much greater as shown by Table 3, although the number of ampere-hours was considerably less than that used in the previous experiments.

TABLE 3

Effects due to Variation in the Circulation of the Electrolyte

[Twenty-four-hour reversals; wrought-iron electrodes; 1 per cent NaCl solution electrolyte]

State of electrolyte	Electrolytic corrosion	Current	Coefficient of corrosion
	Grams	Amp.-hrs.	
Stirred	45.45	97.1	0.45
Sand saturated	32.45	97.1	.32

The electrode surrounded by the moving solution had a loss corresponding to a coefficient of corrosion of 0.45, while the other gave 0.32, the difference due to stirring thus being even more evident on the slow reversals than on the high frequencies. If only the current discharged by each electrode as anode were considered, the coefficient of corrosion in the stirred solution was 0.90, and that in the confined electrolyte was 64 per cent.

The foregoing results show that the free circulation of the electrolyte has a pronounced effect on the coefficient of corrosion, and that this effect is greater the lower the frequency of alternation of the current. They show that the low corrosion coefficient on alternating current is not determined solely by the speed of the reactions and the frequency of alternations. A more probable explanation is that the corrosion during any half cycle in which the electrode is anode takes place nearly in accordance with Faraday's law, as in the case of direct current, but that during the succeeding half cycle when the electrode is cathode a large part of the corroded metal is electroplated back on the electrode. The increased corrosion due to circulation of the electrolyte would be expected under this theory, since the convection currents in the liquid would carry away from the electrode surface a part of the metal that has been corroded during the half of the cycle when the electrode is anode, thus preventing as complete a redeposition during the succeeding half cycle as would otherwise occur. In particular these convection currents in the electrolyte would bring

into contact with the metallic ions, oxygen or other chemicals which would tend to form insoluble compounds, thus rendering the corrosive process irreversible.

Accepting the above theory we would expect that in the case of iron or lead buried in soils, in which circulation of the electrolyte is greatly restricted, the corrosive process would be in large degree reversible even with much longer periods of reversal than in the case of liquid electrolytes, and it seemed possible that this condition might prevail even where the period of the cycle is several

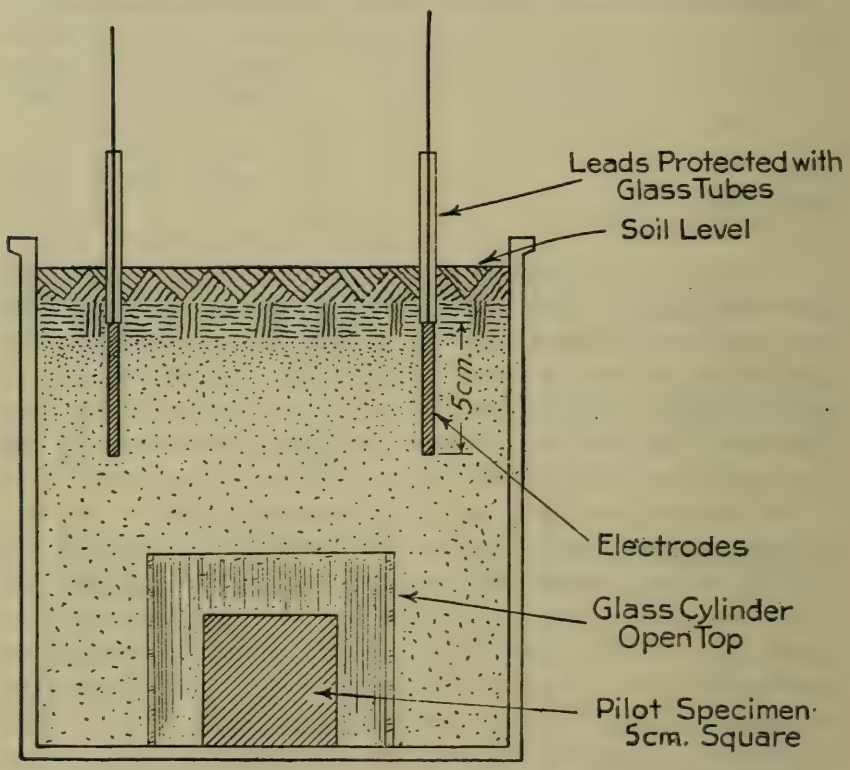

FIG. 3.—*Arrangement of electrodes and check specimen in A. C. electrolysis tests*

minutes or longer, as in the case of the polarity of buried pipes in many localities as mentioned above. This was found to be actually the case, as the following-described experiments show.

2. COMPLETE SERIES OF TESTS

(*a*) **Arrangements.**—With the results of the above experiments in view, a more complete series of tests was planned. Since there is considerable variation among individual specimens, it was recognized that quite a number of specimens under each frequency

would be necessary in order to get a fair average. The specimens were arranged in cells having two current-carrying electrodes and one specimen subjected only to soil corrosion, this specimen being protected from the flow of current by a glass cylinder, as shown in Fig. 3. In a few cases the effect of adding sodium carbonate to the soil was studied. For convenience, the greater part of the tests were made in jars in the laboratory, but a number were made in specimens buried in soil out of doors, in order to check the results obtained in the laboratory. The agreement between the results under the two conditions was found to be satisfactory. The entire series is outlined in Table 4 below.

TABLE 4

Summary of Tests

(a) DIMENSIONS OF ELECTRODES

Electrodes	Indoor	Outdoor
	cm	cm
Iron	5 by 5 by 0.5	20 by 20 by 0.2
Lead	5 by 5 by 0.2	15 by 15 by 0.4

(b) FREQUENCIES USED AND NUMBER OF SPECIMENS USED FOR BOTH IRON AND LEAD

Frequency of reversal	Number of indoor specimens		Outdoor tests
	Natural soil	Soil with Na_2CO_3	
60 cycles per second	18	18	3 large; iron only.
15 cycles per second	18	.....	
1-second cycle	18	18	3 large; iron only.
6-second cycle	18	.....	
1-minute cycle	18	.....	
5-minute cycle	18	.....	
10-minute cycle	18	18	
1-hour cycle	18	.....	
2-day cycle	18	.....	
2-week cycle	18	18	
Direct current	18	18	3
Total	198	90	9 large.

Grand total for iron	297
Grand total for lead	291
Grand total for all tests	588

(*b*) **Electrolyte.**—In determining the coefficient of corrosion with different frequencies of current reversal it is desirable to simulate operating conditions as nearly as is feasible in a complete

and general test. For this reason soil was selected as the electrolytic medium rather than water, which contains the soluble constituents found to exist in soil by chemical analysis. Conditions of circulation of the electrolyte and the electrolytic transfer in it are very different than in soil. The soil used was natural soil near the Bureau of Standards, a light clay having a resistance of 8000 ohms per centimeter cube at approximate saturation. It will support a good vegetable growth and is a fairly normal soil. Soil from the same locality was used in the experiments described in a previous Bureau of Standards' report[6] and a coefficient of corrosion of 100 obtained on iron at a definite current density.

(*c*) **Conditions of the Tests.**—Some of the tests were run in the soil out of doors with natural drainage and aeration. Although it was considered very desirable to make a number of such tests, to run a complete series in outside soil would have been very difficult on account of interference by weather, difficulty of getting electrical connections to many electrolytic cells, and especially the insulating of the various sets from each other, which would be necessary in order to determine the current actually entering or leaving each specimen. The cells used in the inside laboratory tests were 1 gallon (3.8 liters) earthenware jars filled with soil to about 3 cm from the top (about 3 kg), kept practically saturated by adding a quantity of distilled water every day. The tops were left open that evaporation and aeration might go on in a normal way.

(*d*) **Chemicals.**—Since some soils vary widely in chemical constituents, and these may have a pronounced effect on the rate of corrosion, it seems desirable to vary those constituents in the soil which may be expected to affect the corrosion. As indicated by preliminary tests, sodium carbonate (Na_2CO_3) has a very considerable effect on the electrolytic corrosion of both iron and lead; moreover, sodium is a common element in soil, as are carbonates, and this combination is quite soluble, which makes it a satisfactory compound to use in the soil, 0.5 per cent being added to certain cells, as shown in Table 4.

(*e*) **Electrodes.**—Since iron and lead are the two metals commonly serving as underground electrical conductors exposed to soil they were selected as the materials for specimens in these tests. The above-mentioned report shows that the corrosion of different kinds of iron does not differ by large percentages under the conditions of these tests, and since "American iron," which is Besse-

[6] McCollum and Logan, Electrolytic Corrosion of Iron in Soils, Technologic Paper No. 25.

mer-process steel, is obtainable in convenient form, it was adopted. This material was fine-grained and quite pure, having about one-tenth per cent carbon and no slag. The lead was commercially pure and on analysis was found to contain traces of tin or antimony. Indoor specimens were 5 by 5 cm square, the iron being about 0.5 cm thick and the lead 0.2 cm thick. The outdoor iron specimens were 20 cm square and about 0.2 cm thick.

The mill scale and oxide left on the materials in the process of manufacture was not removed, since it was felt that with alternating current the surface might affect the corrosion considerably more than with direct current. The leading-in wire was soldered to a corner of each specimen and a number stamped on the same corner. It was then weighed and a glass tube put over the lead and the tube was then sealed with pitch and the lead attachment and number covered with the same material. This type of connection failed in very few instances, due to corrosion, and the tube and pitch were easily removed with toluol before the specimen was reweighed.

(*f*) **Frequency.**—In determining the frequency of reversal of current two things must be considered: First, the frequencies found in practice; and, second, the completeness of the series, so that a suitable curve could be obtained showing the relation between the corrosion coefficients and the frequency of reversal of current. The standard lighting frequency 60 cycles is available, and 15 cycle was adopted as about the lowest frequency proposed for power work. To obtain the slow reversals a reversing commutator machine was built which is described in detail later. It gave periods of 1 second, 6 seconds, 1 minute, 5 minutes, 10 minutes, and 1 hour. The short periods of reversal were adopted because reversals of polarity of such frequencies commonly occur in the usual operation of a street-railway system as pointed out above. Daily and weekly reversals and direct-current tests were also made. The direct-current specimens serve as a check on the theoretical coefficient of corrosion.

(*g*) **Current Density.**—The density of the current flowing to or from the plates was intended to be such as to produce approximately 1.00 as the coefficient of corrosion with direct-current electrolysis. This is shown in Technologic Paper No. 25 of the Bureau of Standards above referred to, to be about 0.5 milliampere per square centimeter for iron, and approximately this value was used on both the indoor and outdoor specimens.

(*h*) **Length of Run.**—The tests were continued until enough effect was produced to permit of accurate determination of the differences in weight of the specimens before and after test. It was also intended that one of the tests should be continued until a state of equilibrium was reached in the cell; that is, until the rate of corrosion was not changing rapidly as might be the case during the first few cycles of current. Moreover, the cells should not be run to an exhaustion of the soluble chemicals, their concentration being probably closely related to the amount and rate of corrosion occurring on the electrodes. Since the current density is the same in all cases, this rate will depend on the frequency of reversal, and since the coefficient of corrosion is less on the higher frequencies, these must run fully as long as the lower frequencies in order to obtain sufficient weight differences. A period of 15 to 20 days has been found to produce sufficient differences in weight, and no indication that the composition of the soil except that very close to the electrodes had been changed decidedly.

(*i*) **Accidental Variables.**—Other possible variables that have received attention during the experiments were maintained as nearly constant as possible. The temperature did not vary widely from 20°, there being very little heating by the current at the voltage and current density used. The depth was maintained about 10 cm below the surface in the indoor tests and about 40 cm in those outside the laboratory.

(*j*) **Cleaning Electrodes.**—After each run was completed it was necessary to remove the end products of the corrosion process, and since they adhered firmly in some cases special methods were necessary. Iron specimens were cleaned by making them cathode on a 10-volt circuit in a 2 per cent sulphuric acid solution, as described in Technologic Paper No. 25 of the Bureau of Standards. This was found to be very effective and did not attack the iron enough to show on the balances used. The lead specimens were cleaned by immersing them in a solution containing 5 per cent oxalic acid and 1½ per cent of nitric acid. The corrosion products became lead oxalate—a white flocculent substance which was easily removed by brushing. It was found in some cases where the amount of corrosion was large and adhered very firmly that this process was very slow and did not remove the corroded products entirely. Unoxidized specimens weighed before and after immersion in this lead-cleaning solution were found to have lost less than 5 milligrams, the limit of the balances used.

3. EQUIPMENT

(*a*) **Current Sources.**—Sixty-cycle current was obtained from the city power mains while the 15-cycle current came from a small inverted rotary converter. Transformers were used in both circuits to raise the voltage so that a number of cells could be operated in series and so that the primary side would be clear of ground. For the slower reversals of current on the indoor tests power was obtained from the regular three-wire lighting bus bar and commutated by the machine described below. For the outdoor tests for slower reversals and for direct current a small motor-generator set was used. A no-current indicator was used on the alternating-current circuits while a recorder showed what had occurred on the direct-current circuit and those of long period at all times.

(*b*) **Commutating Machine.**—The commutating machine through which the intermediate frequencies were obtained consisted of a series of six commutators each having four brushes and two equal semicircular commutator segments, giving two complete cycles per revolution, driven by gears having such ratios that with the first or highest speed commutator rotating once in two seconds the succeeding commutators made complete current cycles in 6 seconds, 1 minute, 5 minutes, 10 minutes, and 1 hour. This machine was driven by a constant-speed motor.

(*c*) **Resistance.**—In order to obtain the correct current density discharged from the electrodes the resistance of the circuits had to be varied. This was done in part by placing cells in series in groups and paralleling these groups. Rheostats or tungsten lamps were then used to get final adjustments, but no great effort was made to keep the current discharge at exactly 0.5 milliamperes per square centimeter since a small variation in current density does not affect the rate of corrosion. Tungsten lamps with their high positive temperature coefficient are very satisfactory for use in such circuits, since within a certain range they tend to automatically maintain the current at a constant value.

(*d*) **Current Measurements.**—Observations of current were made every day, and more frequently when the current values were changing appreciably. A standard milammeter having a resistance of 0.34 ohm was used for all frequencies above one second. For alternating-current measurements a thermoammeter consisting of a heating element, thermocouple, and millivoltmeter was used. The resistance of this meter amounted to about 7 ohms

and was noninductive. When this meter was introduced in circuits, the effect on the current flow was negligible because of the high resistance of the circuits and it was very easy to correct for this small noninductive resistance by inserting an equal amount in each circuit when the meter was not in use. This meter was used to measure larger currents in the outdoor specimens by means of a shunt. A suitable ampere-hour meter was not available.

4. CORRECTION AND REDUCTION FACTORS

Since chemical corrosion, according to Faraday's law, is proportional to the average current flowing, and since all alternating-current values as observed are effective values rather than average, the current flow has been corrected by dividing the same by 1.11, the ratio between effective and average values of sine-wave current. Since the current flowing with the longer time reversals is controlled by a commutating machine or switch the wave is flat-topped and no such correction is necessary. However, the current was off when controlled by the commutating machine 6 or 7 per cent of the time and this correction was applied to all such values. In order to correct any error due to a possible difference in the length of succeeding one-half cycles, the connections to the commutator controlling each test were reversed at regular intervals, e. g., the 1-second commutator was reversed through the 10-minute commutator and the 1-hour one by a switch every 24 hours. In calculating the theoretical amount of corrosion, the corrosion products of both iron and lead were taken to be divalent and the quantity corroded per ampere-hour is then 1.04 grams for iron and 3.86 grams for lead.

5. ACCURACY OF RESULTS

The accuracy which can be obtained in corrosion experiments of this kind is limited by a number of factors: First, the consistency of the corrosion action itself, which it has been found may vary within wide limits under apparently similar conditions; and second, the limits of measurement. The electrical measurements are correct to about 1 per cent while the time measurements are not in error more than a half per cent. The error due to weighing of single specimens was small, since it was carried to the fourth or fifth place, but in some cases the losses were small and this difference was correct to only the second or third place. This is true of practically all pilot specimens which were subjected only to natural corrosion. Therefore it is evident that the accu-

racy of the results is greater when the amount of corrosion is large The combined accuracy of all measurements was much greater than the consistency to be expected in the corrosive processes.

6. DESCRIPTION OF EACH RUN

The above description of the general condition of the tests is intended to apply to all the following data, and it will be necessary to describe each run only very briefly, deferring until later the presentation of the results.

(*a*) **Sixty-Cycle Tests.**—The 60-cycle tests were run with both iron and lead specimens for the indoor tests and iron for the outdoor tests. Both natural soil and soil with 0.5 per cent sodium carbonate added were used for the indoor tests. It will be noted from the tables presented below in this as well as in other runs that the natural corrosion losses have been rather large on the iron pilot specimens. This is due to the fact that the mill scale was not removed from these specimens before the tests were started and that the cleaning process removed this scale as well as the oxide that was formed during the test. This rather obscures the comparative effect of natural soil and sodium carbonate, but it is still evident, as in the earlier tests, that the natural corrosion loss of iron is greater in natural soil while the electrolytic corrosion is greater in the chemical soil. In fact, in almost every instance the natural loss was greater than the electrolytic loss in the natural soil, and in 5 of the 12 specimens also in the chemical soil.

With the three large specimens used in the outdoor tests the natural loss was considerably less than the electrolytic loss, and the coefficient of corrosion is only slightly less than 1 per cent.

(*b*) **Fifteen-Cycle Tests.**—The 15-cycle tests were run with lead and iron in soil only, these cells being in series with about 310 volts, giving about 25 volts per cell. In every case except four iron electrodes the electrolytic losses were all greater than the natural corrosion in the same cells.

(*c*) **One-Second Period.**—Iron and lead specimens in both normal soil and soil with sodium carbonate were used in the tests with 1-second period, the cells being divided into four groups of three each in series. In two cases the iron electrodes lost more than the pilot specimens, but on the average the losses were greater than in the preceding tests. Iron specimens were placed in outdoor soil for these tests, and in this instance the natural corrosion is unusually high because the specimens were left in the ground without current for a considerable time.

(*d*) **Six-Second Period.**—Normal soil alone was used in these tests, there being three groups of cells and four cells in each group. Approximately 12.5 volts existed across each cell in order to maintain the current at about 30 milliamperes or 0.5 milliampere per square centimeter.

(*e*) **One-Minute Period.**—In the one-minute reversals iron and lead electrodes were used in natural soil connected in three groups of four cells each. Approximately 9 volts were maintained across the cells containing the iron electrodes and 14 volts on the lead electrodes. In case of the iron electrodes there was a consistently greater loss on the odd electrode than on the even, the reason for which is not altogether evident since no such consistency exists on the lead specimens; and as the two sets were in series, it is therefore not due to unbalanced or unequal half cycles.

(*f*) **Ten-Minute Period.**—Both iron and lead specimens in natural soil and soil containing sodium carbonate were used in the 10-minute period tests. The cells were divided into four groups of six each. It will be noted that the corrosion of iron in natural soil is here greater than in the chemical soil, and the reverse is the case with the lead specimens.

(*g*) **One-Hour Period.**—Only natural soil was used in the one-hour reversals, about 15 volts being impressed on each pair of electrodes.

(*h*) **Forty-Eight-Hour Period.**—Natural soil alone was used in the daily reversals (48-hour period) with iron and lead electrodes, the entire set being in series on 240 volts. The iron specimens had a voltage of about 15 volts on each pair and the lead electrodes about 13 volts. In the case of the iron specimens, the odd and even specimens, or those anode first or anode last in the test show no great or consistent difference as was noted in the preliminary tests, and the lead specimens show an opposite effect from that noted at that time; that is, the electrodes which were anode during the first half cycle have lost more than those which were cathode initially.

(*i*) **Weekly Reversals.**—Both natural soil and soil containing sodium carbonate were used in the weekly reversals (two-week period) and the entire set was connected in series on 240 volts. The voltage across the iron specimen cells in the natural soil was about 15 volts per cell and about 9 volts in the chemical soil. With the lead electrodes the average voltage was less than 12 across each cell in the natural soil and less than 4 in the chemical soil.

(*j*) **Direct-Current Tests.**—The direct-current tests were carried on with iron and lead specimens both indoors and outdoors, and in the indoor tests with sodium carbonate in the soil as well as natural soil. The indoor cells were connected in four groups of six each with 230 volts impressed on them. The ampere-hours varied in the different groups from 8 to 12. With the iron specimens the anode losses are large, the coefficient of corrosion being approximate unity, while the cathode specimens lost less than the pilot specimens, evidently because of the protective effect of the current. In the lead specimens, however, the anode losses are far below what might be theoretically expected, while the cathodes lost less in the natural soil than the pilot specimens, but more in the soil containing sodium carbonate. This is due not so much to an increased electrolytic loss in the chemical soil, but to a greatly decreased natural loss. Since the loss in the lead specimens was so much less than might be expected, another set was run under practically the same conditions but with the current maintained more closely at 0.5 milliampere per square centimeter. These results, however, corroborate the work previously done. The outdoor tests were conducted on both lead and iron with the large plates mentioned above. The protective effect of the current is noted again on the iron specimens. In the lead specimens 12 anodes were used, the lead in this case being sections of lead-sheath cable, 6 of which contained about 1 per cent antimony while the other 6 contained only traces of tin and antimony. Two pilot specimens of each composition were used. These tests further corroborated the results of the indoor tests in that the coefficient of corrosion of lead on direct current was low.

7. DISCUSSION OF RESULTS

Tables containing the summary of the results of the above-mentioned tests are given below. These tables are arranged in halves with losses in grams above and the coefficient of corrosion below with the frequency or period of reversal in the first column, the average loss of six specimens in each of the three succeeding columns (the first being the odd numbered electrodes and the second the even numbered electrodes and the third the pilot specimens). From these are calculated the electrolytic loss of odd or even electrodes shown in the fifth and sixth columns, and the seventh column contains the average electrolytic loss of all electrodes. Below the frequency is repeated and the next column contains the average quantity of electricity in ampere-hours flow-

ing through the specimens. Following this are four columns giving the coefficient of corrosion. The coefficients of corrosion of the odd electrodes and even electrodes are first given, then the coefficient of corrosion based on one-half the current or that while each electrode was positive, and last that based on the average loss and the total current through the cells. Since it is difficult to draw any conclusions from the electrode losses shown without also considering the ampere-hours, the coefficients of corrosion will give us the best idea of results, and these are shown in both the tables and curves.

(*a*) **Indoor Tests—Iron in Normal Soil.**—In Table 5 a summary of the results obtained using iron electrodes in indoor cells containing normal soil is given.

TABLE 5

Summary of Alternating Current Electrolysis Tests—I

[Variable, frequency of reversal; indoor tests; iron electrodes; soil electrolyte]

Period of cycle	Total loss			Electrolytic loss		
	Odd electrodes	Even electrodes	Pilot	Odd electrodes	Even electrodes	Average
	Grams	Grams	Grams	Grams	Grams	Grams
60-cycle	1.480	1.289	1.645	−0.165	−0.356	−0.261
15-cycle	1.036	.862	.834	+ .202	+ .028	+ .115
1-second	1.064	1.190	.640	.424	.550	.488
6-second	.960	1.046	.566	.394	.480	.437
1-minute	2.024	2.077	1.203	.821	.874	.848
5-minute	1.907	1.398	.748	1.159	.650	.904
10-minute	2.522	2.252	.901	1.621	1.351	1.486
1-hour	3.134	2.941	1.165	1.969	1.776	1.872
2-day	5.490	5.124	1.130	4.360	3.994	4.177
2-week	8.349	9.680	1.387	6.962	8.293	7.627
Direct-current	9.697	.139	1.023	8.674	.....	.....

Period of cycle	Current discharge (amp. hours)	Coefficient of corrosion			
		Odd electrodes	Even electrodes	On basis of anodic current	On basis of total current
60-cycle	16.05	−0.0198	−0.043	−0.031	−0.0156
15-cycle	13.32	+ .0292	+ .0004	+ .016	+ .008
1-second	17.99	.045	.059	.046	.023
6-second	16.83	.045	.055	.050	.025
1-minute	19.25	.082	.087	.084	.042
5-minute	19.99	.111	.063	.087	.043
10-minute	16.48	.189	.158	.173	.087
1-hour	18.40	.206	.186	.197	.098
2-day	27.22	.308	.282	.295	.148
2-week	23.17	.58	.69	.633	.316
Direct-current	9.82	.85	.....	.....	.850

As mentioned earlier, it will be seen that the pilot-specimen loss is quite large and that there is considerable variation under the different frequencies. This is evidently a real variation due to a difference in soil action, because it was found that in individual cases when the pilot-specimen corrosion varied considerably from the average the current-carrying electrodes would also vary in the same direction. The coefficient of corrosion only in the case of the 60-cycle tests is negative. The electrodes were numbered consecutively, an odd number and a succeeding even number being grouped in each cell. The difference in the coefficient of corrosion between the odd and even electrodes is rather large in some cases; for example, in the 5-minute specimens the coefficient is 0.116 for the odd electrodes and only 0.065 for the even, and in the 15-cycle test the per cent discrepancy is large, although the values in grams do not differ greatly. The direct-current test shows a coefficient of only 0.85, which is rather low, and this can only be explained as being probably due to the effect of the iron oxide serving as a protection rather than accelerating the corrosion. The next to the last column is simply double the one succeeding or an average of the odd and even electrode coefficients.

(*b*) **Indoor Tests—Iron Electrodes in Soil with Sodium Carbonate.**—In Table 6, containing the results on iron electrodes in sodium carbonate soil, it will be noted that in the case of the 60-cycle run the coefficient of corrosion is positive but that the values in the other cases of reverse currents are smaller than in the natural soil. In the 2-week test the odd-electrode loss is considerably less than the even, supporting the theory that in these longer time reversals the electrodes which are positive last suffer the greater loss. Under these conditions the direct-current loss is very nearly 100 per cent.

TABLE 6

Summary of Alternating Current Electrolysis Tests—II

[Variable, frequency of reversal; indoor tests; iron electrodes; soil and sodium carbonate electrolyte]

Period of cycle	Total loss			Electrolytic loss		
	Odd electrodes	Even electrodes	Pilot	Odd electrodes	Even electrodes	Average
	Grams	Grams	Grams	Grams	Grams	Grams
60-cycle	1.390	1.373	1.199	+0.191	0.174	+0.182
1-second	.865	1.146	.677	.188	.469	.329
10-minute	1.617	1.532	.835	.782	.679	.739
2 week	7.922	9.081	1.636	6.286	7.451	6.868
Direct-current	10.423	.172	.819	9.604		

TABLE 6—Continued

Summary of Alternating Current Electrolysis Tests—II—Continued

Period of cycle	Current discharge (amp. hours)	Coefficient of corrosion			
		Odd electrodes	Even electrodes	On basis of anodic current	On basis of total current
60-cycle	16.05	0.023	0.021	0.022	0.011
1-second	17.99	.020	.050	.035	.018
10-minute	16.48	.091	.081	.086	.043
2-week	23.17	.52	.62	.57	.285
Direct-current	9.82	.94	.....	.....	.94

(*c*) **Indoor Tests—Lead Electrodes in Soil.**—With lead electrodes in soil very regular results were obtained. In Table 7 the loss is shown to be increasing gradually from 60 cycles to 2 weeks with only one discrepancy, the loss on the even electrode (see p. 24) in 2-day reversals being considerably smaller than on the 10-minute and 1-hour specimens. The products of corrosion seem to be increasing the effect on the pilot specimens, as it will be noted that the loss is increasing as the frequency decreases. However, the most remarkable facts concerning these tests is that the odd electrodes, those which were initially positive in the tests, lost considerably more than the even electrodes in both the 2-day and 2-week test. The other remarkable feature is the small coefficient of corrosion exhibited in the case of the direct-current test. Since in the first set weighed the losses were so small (only 22 per cent of the theoretical), a second run was made and a coefficient of 25.4 per cent obtained, practically the same as before. This indicates that under the conditions of these tests and probably under most soil conditions the corrosion of lead is very considerably less than it has been formerly considered to be.

TABLE 7

Summary of Alternating-Current Electrolysis Tests—III

[Variable, frequency of reversal; indoor tests; lead electrodes; soil electrolyte]

Period of cycle	Total loss			Electrolytic loss		
	Odd electrodes	Even electrodes	Pilot	Odd electrodes	Even electrodes	Average
	Grams	Grams	Grams	Grams	Grams	Grams
60-cycle	0.325	0.328	0.124	+0.201	+0.204	0.202
15-cycle	.342	.332	.133	.209	.199	.204
1-second	.385	.354	.118	.267	.236	.252
6-second	.518	.528	.098	.420	.430	.425
1-minute	2.860	2.845	.652	2.208	2.193	2.200
5-minute	3.868	3.634	.406	3.462	3.228	3.345
10-minute	3.468	3.738	.341	3.127	3.397	3.262
1-hour	5.886	5.771	.901	4.985	4.870	4.928
2-day	8.719	5.072	1.357	7.362	3.715	5.538
2-week	13.710	7.789	1.176	12.634	6.713	9.674
Direct-current	12.319	.....	.937	11.382	.....	11.382
Do	13.574	.....	.882	12.692	.....	.....

Period of cycle	Current discharge (amp. hours)	Coefficient of corrosion			
		Odd electrodes	Even electrodes	On basis of anodic current	On basis of total current
60-cycle	16.05	0.0065	0.0066	0.0065	0.0033
15-cycle	13.32	.0082	.0077	.0080	.0040
1-second	14.87	.0093	.0082	.0088	.0044
6-second	16.83	.0129	.0132	.0131	.0065
1-minute	19.25	.059	.059	.059	.030
5-minute	19.99	.089	.085	.086	.043
10-minute	14.95	.108	.118	.112	.056
1-hour	18.40	.140	.137	.139	.069
2-day	27.22	.140	.071	.105	.053
2-week	23.17	.282	.150	.216	.108
Direct-current	13.40	.220	.....	.....	.220
Do	12.93	.254	.....	.....	.254

(*d*) **Indoor Tests—Lead Electrodes in Sodium Carbonate.**—The losses of lead electrodes in sodium carbonate (Table 8) are greater than in the normal soil, the difference being especially noticeable in the longer reversals and in the direct-current tests. For example, in the weekly reversals the coefficient of corrosion in normal soil was 0.108 while in the sodium carbonate it was 0.172; the direct-current coefficient of corrosion has risen from about 25 per cent to 34 per cent.

TABLE 8

Summary of Alternating-Current Electrolysis Tests—IV

[Variable, frequency of reversal; indoor tests; lead electrodes; soil and sodium carbonate electrolyte]

Period of cycle	Total loss			Electrolytic loss		
	Odd electrodes	Even electrodes	Pilot	Odd electrodes	Even electrodes	Average
	Grams	Grams	Grams	Grams	Grams	Grams
60-cycle	0.555	0.542	0.077	0.478	+0.465	0.471
1-second	.316	.630	.062	.254	.568	.411
10-minute	4.019	3.844	.110	3.909	3.734	3.822
2-week	17.356	13.487	.111	17.245	13.370	15.307
Direct-current	17.726	.....	.075	17.651	.....	17.651

Period of cycle	Current discharge (amp. hours)	Coefficient of corrosion			
		Odd electrodes	Even electrodes	On basis of anodic current	On basis of total current
60-cycle	16.05	0.0154	0.0150	0.0152	0.0076
1-second	14.87	.0088	.0198	.0143	.0071
10-minute	14.95	.135	.129	.132	.066
2-week	23.17	.386	.299	.344	.172
Direct-current	13.4	.340	.....	.....	.....

(*e*) **Outdoor Tests—Iron and Lead Electrodes in Soil.**—The outdoor tests shown in Table 9 are not extensive, but the cases given show reasonably good agreement with the indoor tests given above. The coefficient of corrosion at 60 cycles is slightly less than 0.01 for iron electrodes and the direct-current loss is 0.70. Considering only the direct-current tests on iron, it was noted that as the voltage necessary to maintain the current at 0.5 milliampere per square centimeter became greater the coefficient of corrosion decreased. For example, we find a coefficient of corrosion of 0.96 for iron electrodes in sodium carbonate soil and 0.85 in normal soil on the indoor tests and only 0.70 for the outdoor tests and the potential has varied from about 10 volts on the first to 35 on the last test.

TABLE 9

Summary of Alternating Current Electrolysis Tests—V

[Variable, frequency of reversal; outdoor tests; iron and lead electrodes; soil and sodium carbonate electrolyte]

Period of cycle	Total loss			Electrolytic loss			
	Odd electrodes	Even electrodes	Pilot	Odd electrodes	Even electrodes	Average	
	Grams	Grams	Grams	Grams	Grams	Grams	
60-cycle	2.65	2.60	0.97	1.68	1.63	1.65	Iron
1-second	9.06	7.30	5.94	3.12	1.36	2.24	Iron
Direct-current	41.96	1.73	4.61	37.35	37.35	37.35	Iron
Do	871.86	.....	6.22	865.64	.....	865.64	Lead

Period of cycle	Current discharge (amp. hours)	Coefficient of corrosion				
		Odd electrodes	Even electrodes	On basis of anodic current	On basis of total current	
60-cycle	155.4	0.0203	0.0197	0.0192	0.0096	Iron
1-second	102.0	.0589	.0256	.0431	.0215	Iron
Direct-current	51.6	.700	.700	.700	.700	Iron
Do	1034.0	.....	.217	.217	.217	Lead

8. CURVES

The data shown in the above tables have been plotted in curves in which the ordinates are coefficients of corrosion expressed in per cent and the abscissas are the logarithms of the number of seconds required for one complete cycle. Fig. 4 shows the data obtained with iron electrodes, this being based on the average electrode loss and the total current flowing in any one direction through the cells. The coefficient is therefore based on the total current discharged by one electrode. It will be noted that the curve for the coefficient in natural soil is above that for soil containing sodium carbonate, except the last point for direct current, when the latter shows the greater loss. The values begin to rise quite rapidly at about the 10-minute cycle, and reach a maximum in the direct-current test, the value for which is placed arbitrarily as far as the time is concerned. It is very interesting to note that even in the case of a cycle of two weeks' duration the coefficient of corrosion is only about 0.6 and on a two-day cycle only 0.3 of its value for direct current.

Fig. 5 contains the same data on lead electrodes, and here it is seen that the soil containing sodium carbonate produces a consistently higher coefficient of corrosion than the natural soil, just the reverse of the condition with iron electrodes. The tendency to rise is noticed at an earlier point or a higher frequency than with the iron, beginning with about the one-minute cycle, and at a cycle

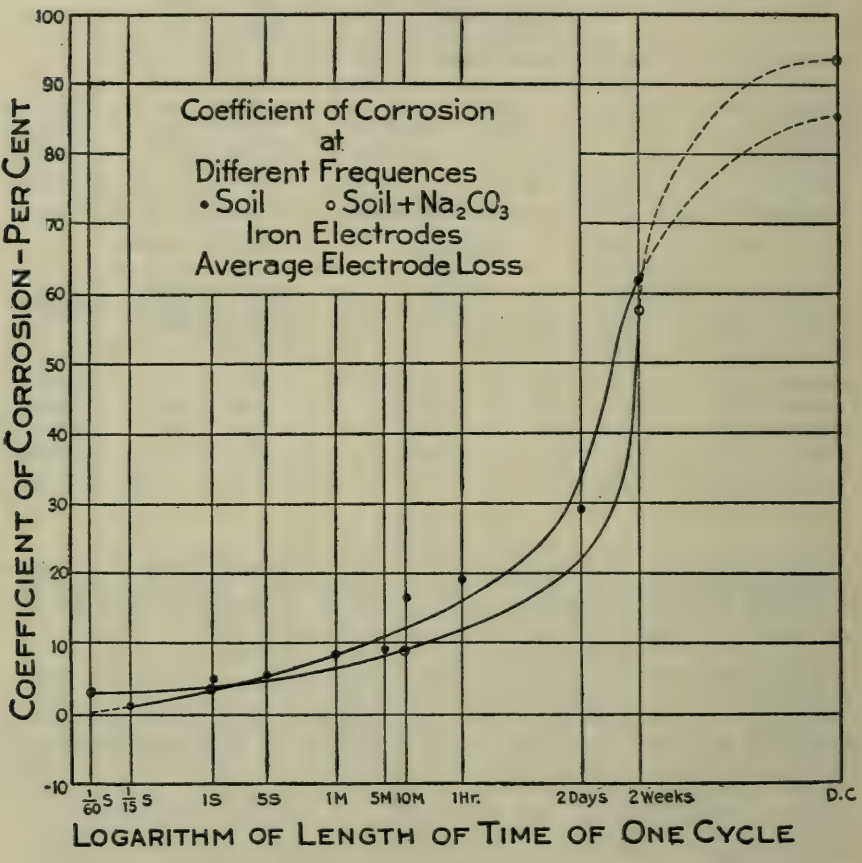

Fig. 4

of two weeks' duration the coefficient of corrosion has reached the same value as for direct current.

9. SUPPLEMENTARY TESTS

Since certain authors have pointed out the fact that the wave form of alternating current is affected when passing through an electrolytic cell, and since a material change in such wave form would affect the current measurements, an oscillograph was used

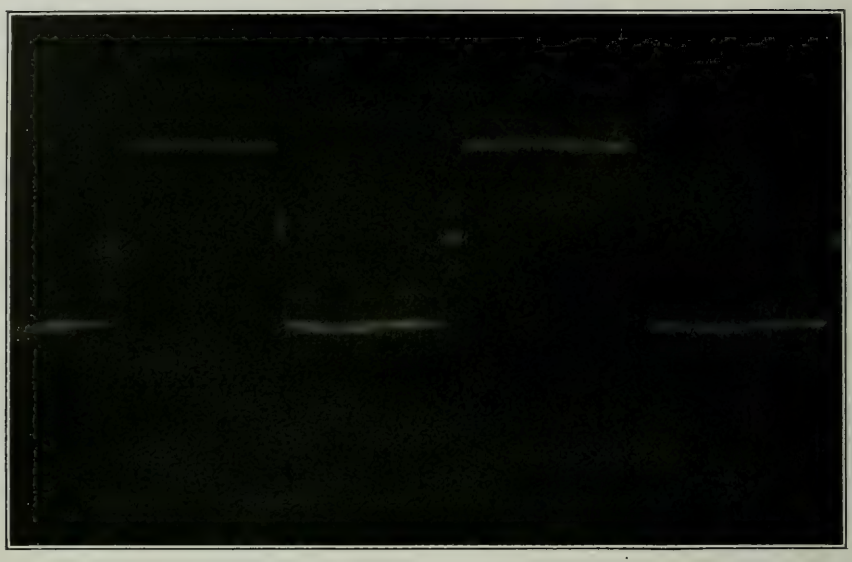

FIG. 6.—*Wave shape for one-second cycle*

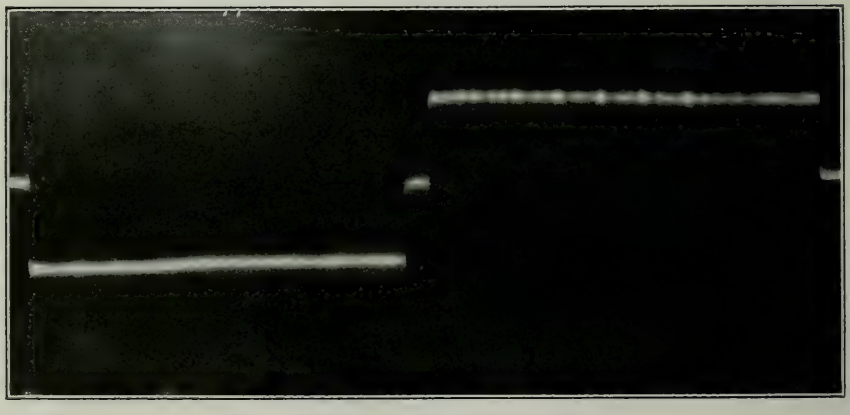

FIG. 7.—*Wave shape for six-second cycle*

to determine the wave form of current passing through the cell and its relation to the potential wave impressed on it. It was found that there was no appreciable distortion of the wave shape due to the presence of the cell.

In order to determine the cycle of operation of the commutating machine exactly, the current wave was observed with the oscillograph. It is seen that on the one-second cycle (Fig. 6)

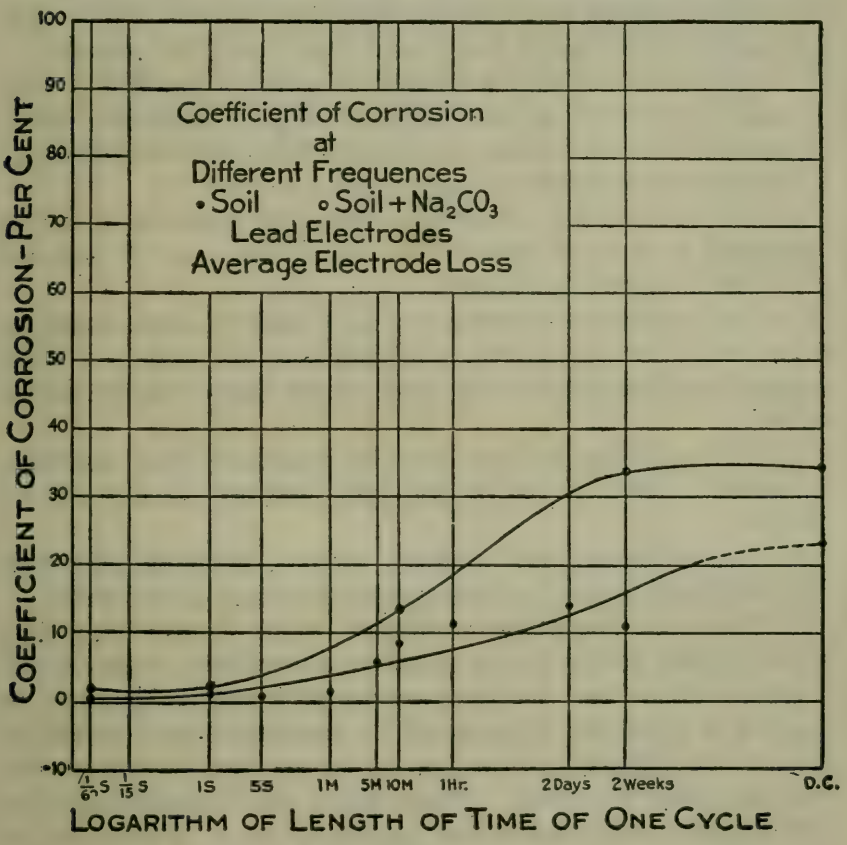

FIG. 5

the current increases slightly during about the first one-fourth second and falls during the remainder of the half cycle. In the six-second cycle (Fig. 7) this rise and fall is seen, and the fall continues for a considerable part of each half cycle, but the waves appear to be so nearly flat top in both the one-second cycle and the six-second cycle that no correction due to the variation between the average value and the effective value need be made.

III. CONCLUSIONS

From the above results certain conclusions may be drawn concerning the corrosion of iron and lead electrodes under usual soil conditions when exposed to the action of periodically reversed current.

1. The corrosion of both iron and lead electrodes decreases with increasing frequency of reversal of the current.

2. The corrosion is practically negligible for both metals when the period of the cycle is not greater than about five minutes.

3. With iron electrodes a limiting frequency is reached between 15 and 60 cycles per second, beyond which no appreciable corrosion occurs. No such limit was reached in the lead tests, although it may exist at a higher frequency than 60 cycles.

4. With periodically reversed currents, the addition of sodium carbonate to the soil reduces the loss in the case of iron and increases it in the case of lead.

5. The coefficient of corrosion of lead, under the soil conditions described in the report, when subjected to the action of direct current, was found to be only about 25 per cent of the theoretical value.

6. The corrosion of lead reaches practically the maximum value with a frequency of reversal lying between one day and one week.

7. The corrosion of iron does not reach a maximum value until the period of the cycle is considerably in excess of two weeks.

8. The most important conclusion to be drawn from these investigations is that in the so-called neutral zone of street railway networks, where the pipes continually reverse in polarity, the damage is much less than would be expected from a consideration of the arithmetical average of the current discharged from the pipes into the earth. Where pipes are alternately positive and negative with periods not exceeding 10 or 15 minutes, the algebraic sum of the current discharged is more nearly a correct index to the total damage that will result than any other figure than can readily be obtained.

9. The reduction in corrosion due to periodically reversed currents appears to be due to the fact that the corrosive process is in a large degree reversible; so that the metal corroded during the half cycle when current is being discharged is in large measure redeposited during the succeeding half cycle when the current flows toward the metal. This redeposited metal may not be of

much value mechanically, but it serves as an anode surface during the next succeeding half cycle, and thus protects the uncorroded metal beneath.

10. The extent to which the corrosive process is reversible depends upon the freedom with which the electrolyte circulates, and particularly on the freedom of access of such substances as oxygen or carbon dioxide, which may result in secondary reactions giving rise to insoluble precipitates of the corroded metal. It is largely for this reason that the corrosion becomes greater with a longer period of the cycle, since the longer the period the greater will be the effect of these secondary reactions.

WASHINGTON, February 14, 1916.

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